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REPORT

of the

FIRST SERVICES-INDUSTRY CONFERENCE ON HIGH TEMPERATURE HYDRAULIC SYSTEMS

26, 27 January 1954

AIRBORNE EQUIPMENT DIVISION
BUREAU OF AERONAUTICS
DEPARTMENT OF THE NAVY
Washington 25, D. C.

BUAER REPORT AE--61-8 PART II

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SPONSORED BY

AIRBORNE EQUIPMENT DIVISION

RESEARCH AND DEVELOPMENT GROUP

BUREAU OF AERONAUTICS

DEPARTMENT OF THE NAVY

IN COLLABORATION WITH

AIRCRAFT LABORATORY

WRIGHT AIR DEVELOPMENT CENTER

DEPARTMENT OF THE AIR FORCE

CHAIRMAN

LEO MORSE CHATTLER

HEAD, ACTUATING AND FLIGHT CONTROL SYSTEMS SECTION

BUREAU OF AERONAUTICS

AGENDA

TUESDAY, 26 JANUARY 1954

0830-0900 - REGISTRATION

TUESDAY AND WEDNESDAY, 26 AND 27 JANUARY 1954

0900-1230 - MORNING SESSION
1330-1700 - AFTERNOON SESSION

WELCOME - - - - - - - - - - - - J. E. Sullivan, Director
Airborne Equipment Division

CHAIRMAN - - - - - - - - - - - - L. M. Chattler, Head
Actuating and Flight Control Systems Section

ASSISTANT CHAIRMAN - - - - - - - B. L. Mettee, High Temperature Project Engineer

AIRFRAME MANUFACTURERS DATA PRESENTATION:

I. Data Presentation Sequence

A. Measured airplane hydraulic fluid temperature data including outside air temperature and compartment temperature.

B. Calculated airplane hydraulic fluid temperature data.

C. Information on materials, finishes, design criteria and tests on 160°F and above components and systems in which the contractor has been engaged.

D. Additional comments and recommendations of each company.

II. Companies to Present Data

A. Omitted because of classification.

III. Group Discussion

The joint USAF-NAVY program on high temperature hydraulic systems as noted in the first, second and third BUAER-WADC Conference Reports will be presented for discussion in the following order:

A. Determination of a standard procedure for obtaining and presenting airplane hydraulic system fluid temperature data.

B. Fluids

C. Packings

D. Pumps

E. Control Valves

F. Relief Valves

G. Actuating Cylinders

H. Filters

I. Accumulators

J. Hose Assemblies

K. Coiled Tubing

L. Tubing and Fittings

M. Other Items

N. System Design Requirements

IV. Coordination Procedures

A. Discussion on establishment of system for interchange of data

B. Discussion on whether or not establishment of a committee to accept assignments is necessary

C. Discussion on additional meetings of this type

IN ATTENDANCE

Bell Airc ft Corporation

R. O. Lang
T. W. Steele
H. E. Wells

Boeing Airplane Company

A. R. Bremer

Chance Vought Aircraft, Incorporated

M. Bland
D. W. Leach
J. W. Ludwig

Consolidated Vultee Aircraft Corporation, Fort Worth

P. S. Kleven

Consolidated Vultee Aircraft Corporation, San Diego

H. Field, Jr.
R. G. Sharp
J. K. Williams

Douglas Aircraft Company, Incorporated gundo

J. T. Burns

Douglas Aircraft Company, Incorporated, Sa Monica

J. J. Martin
D. H. Moreton
F. W. Murphy

Goodyear Aircraft Corporation

A. P. Gordon
A. H. Williams

Grumman Aircraft Engineering Corporation

A. Mead
J. Roukis
A. Weisskopf

Kaman Aircraft Corporation

G. F. Lubben

Lockheed Aircraft Corporation

J. I. Detweiller
R. E. Middleton

McDonnell Aircraft Corporation

D. W. Irwin

Glenn L. Martin Company

P. W. Boone
C. C. Cooke
E. G. Gravenhorst
T. C. Hill

North American Aviation, Incorporated, Columbus

R. E. Kibele
M. Rothgery

North American Aviation, Incorporated, Downey

R. E. Dunn
G. R. Keller
T. Weiner

North American Aviation, Incorporated, Los Angeles

R. C. Bumb
T. N. Oppenheim

Northrop Aircraft Incorporated

W. M. Steffen
W. F. Talbot

Pennsylvania State University

E. E. Klaus

Republic Aviation Corporation

L. Ferens
W. Mayhew
F. Pollard

Sikorsky Aircraft

E. J. Vianney

Naval Air Material Center

G. K. Holmes
R. F. Pagliarini
A. H. Williams

Naval Research Laboratory

V. Fitzsimmons
C. Murphy

Wright Air Development Center - Department of the Air Force

E. R. Bartholomew
R. A. Green
1st Lt. J. A. King
J. C. Magee
R. I. Maguire
F. R. Straus

Bureau of Aeronautics - Department of the Navy

E. D. Armstrong
L. M. Chattler, Chairman
F. C. Christian
S. M. Collegeman
F. F. Jacobs
B. L. Mettee, Assistant Chairman
N. E. Promisel
S. E. Sanfilippo
M. H. Smith
Cdr. R. A. Weatherup

WELCOME

BY

COMMANDER R. A. WEATHERUP

HEAD, MECHANICAL EQUIPMENT BRANCH

AIRBORNE EQUIPMENT DIVISION

FOR

J. E. SULLIVAN

DIRECTOR, AIRBORNE EQUIPMENT DIVISION

Good morning, gentlemen. On behalf of the Bureau of Aeronautics I'd like to welcome you to this conference.

This problem of high temperature has been with us for sometime. I'd like to assure you we've been concerned with it although, I'd like to admit, we haven't given it the attention we should have.

Also, I would like to discuss the very human problem of doing first things first. It now appears we've reached the position where high temperature hydraulics is first.

I think most of you have received copies of the BuAer-WADC conferences. These conferences were instituted in order that we would be sure that the Air Force and the Navy efforts on high temperature hydraulics would be coordinated.

Of course, the success of these meetings is completely dependent on coordination with you people, so as not to get off on a tangent. The express purpose of this meeting is to obtain such coordination. Its success will depend largely on you.

We plan to hold our meetings with the Air Force monthly until we see our way clear in this field. From the agenda you can see we want to first establish what actual temperatures we are encountering in our new airplanes.

Then we would like to coordinate our research and development program, and finally a general discussion of information for the benefit of all.

The success of this meeting is in your hands, and your cooperation will be appreciated.

NOTE

All statements and discussions not pertinent to the subject of high temperature hydraulic systems have been eliminated from this report with the intent of expediting publication. This does cause discontinuity in the reading.

L. M. CHATTLER, Chairman
High Temperature Hydraulic Conference

INTRODUCTION

BY

LEO MORSE CHATTLER

HEAD, ACTUATING AND FLIGHT CONTROL SYSTEMS SECTION

BUREAU OF AERONAUTICS

Good morning, gentlemen. For sometime now we have all been talking about the high temperature problem in aircraft hydraulic systems. In fact some of you have expressed considerable concern about the lack of activity in developing high temperature hydraulic components. In this regard, as Commander Weatherup pointed out, with the limited personnel available in the government units concerned with these systems, we can only do first things first and high temperature hydraulics is now first.

I believe that we all agree that by exerting a joint effort on this problem, we will be able to progress at a greater rate. Thus, this conference was called to bring everyone up to date on the accomplishments of the Airframe Industry and the Services. Also that we may be coordinated in our future efforts.

From the information presented at this meeting and with your concurrence, I expect that we should be able to establish in the minutes of this meeting the following:

1. Upper operating temperature limit of MIL-O-5606 fluid.
2. A second higher temperature limit for new high temperature fluids.
3. A specified fluid for use with the second step temperature range.
4. A complete summary of the airframe manufacturers research, development and test experience on equipment and devices above 160°F.
5. A firm Industry-Services program for developing, testing and producing high temperature hydraulic systems with a very high degree of reliability.

In regard to these temperature limits, I have been concerned for sometime with the fact that people speak about extremely high temperatures in our airplane hydraulic systems and yet I find that the actually measured temperature data on our present day aircraft is very meager. I hope we get some good data during this meeting.

Many companies have taken the approach of "no trouble, why worry about the temperature". This approach may have sufficed in the past, but will not be acceptable for the present or the future. The reasons for this is obvious. With a hydraulically operated flight control system we are no longer in a position to wait for a failure pattern before we fix up our airplanes, because this will mean the loss of aircraft and pilots. We must know what the life of our components is going to be, because, unlike heretofore we will have to establish equipment replacement schedules so that the equipment can be replaced on an airplane before it fails. Thus, we must know what our actual airplane hydraulic system temperatures are.

The actual life of components and our ability to accurately determine this life will have a strong influence on how the airplane systems will be designed. Today we have two schools of thought on flight control systems, for example. Some feel that a 2 pump system where one pump supplies one flight control system exclusively and the other pump supplies a combination alternate flight control and utility system is an adequate system arrangement. Others feel that we should have a 3 pump system so that we have two completely independent flight control systems and an independent utility system. The major reason being that any utility component, and these components are as high in number as 70, when it fails should not fail one part of the dual flight control system. It is obvious that for the former type system, to have any success whatsoever, we need a very high degree of reliability of the hydraulic system.

CONTENTS

PART II A

Information on Materials, Finishes, Design Criteria and Tests on 160°F and above components and systems as presented by the airframe manufacturers.

MR. CHATTLER: We will now continue with Part C of Item I, which is information on materials, finishes, design criteria and tests on 160 degree F and above components and systems in which the contractor has been engaged, and additional comments and recommendations of each company. We will first hear from Mr. Ralph Middleton of Lockheed Aircraft Corporation.

MR. MIDDLETON, LOCKHEED: As far as testing is concerned, we recently started the series of tests looking towards development of suitable packings primarily. We haven't done anything at all on testing of components of pumps or valves.

Our packing consideration we feel would be reasonable to use in some of these spots, which represent hot spots in the airplane and particularly with respect to land seals. We have set up a packing test fixture which consists of a rod without any piston head on it which is cycled through a block which has removable glands at each end so we can put in any type of packing we happen to think of for test purposes, and we can either circulate the fluid through this block or have it static in the block. It's heated by means of electric heaters installed in cavities in the block itself and one heater is within the hole on the rod. This unit is cycled by means of another rod attached to it. We can vary the rate of cycling and the stroke and we can also, at the same time vary the pressure applied hydraulically to the test unit.

We can impulse it or cycle it in any manner seemed desirable. We haven't done much with that system as yet. However, we have used a few preliminaries, using 67 holdings. Also we have teflon back-up rings. Using PRP Los Angeles packing and also Parker packings, a standard approved compound.

The method which we have tentatively arrived at for cycling was a one inch and one cycle per second. We picked a temperature for this test of 400 degrees F feeling it was better to start off with a single temperature and then arrive at a cycling rate which could be kept constant, and hadn't attempted to evaluate the materials available.

So in order to be above any temperature which we could see in the near future for our systems, we picked 400 degrees. The test which we have run at 400 degrees, using this rate of cycling and impulsing the input of fluids so that the pressure impulse of 3000 psi is started simultaneously with the rod. Then at the end of the stroke, the pressure is released and the rod is moved in the other direction for atmospheric pressure. That seemed to give us a means of cycling, which would in some respects approximate what happens in the actuating cylinder. Using this method, we were able to cycle a standard figuration of standard "O" rings and back-ups about 7000 cycles, at which time we got a failure. However, apparently we were getting some leakage which we were unable to evaluate because of the heat and since we were using 5606 fluid we couldn't collect any leakage. So that failure was determined by actual breakdown of the seal which produced a heavy rate of leakage and loss of pressure. The failure in each case consisted of--in the case of the leather--consisted of complete loss of the leather. The "O" ring itself got hard and brittle and had broken apart.

Our next attempt with the standard "O" ring and the teflon back-up rings produced much better results. We were able to get a little over 17,000 cycles on it at which time the selector valve failed and we had to stop that particular test and since a certain amount of soaking statically at the temperature occurs, we discontinued that test and started out with new packings because we feel at some time during the course of our testing we want to introduce another test where we do have a soaking period statically interposed between a number of cycles and a certain number of minutes static.

Based on what we have observed in the one airplane, we feel that the static soaking may have a bearing on the packing life. We have been playing around to some degree with the static seals, metallic static seal, which was recommended to us by Wright Field, and so far we haven't gone far enough with it to tell much about it. We have had difficulty getting parts made. Static seals have, in general, given us quite a bit of trouble, particularly in this hot section in the airplane. We have had in actual number more static seal failures than we have had dynamic seal failures. Of course, percentage-wise, that isn't true, because there are more static seals in the system.

In an attempt to evaluate that, we have run a series of tests where we have not impulsed it but have just soaked it. And we had temperatures ranging from 160 to 300 degrees. 160, 230 and 300 were the three temperatures used for various lengths of

time, from one day through seven days, examining one sample seal each 24-hour period.

In the course of that evaluation we tried most of the various high temperature compounds which were recommended to us by Linear, by Parker and by Plastic Products. Those were tried along with samples of the standard compounds.

In every case the appearance of the seal and its physical properties at the end of even 24 hours at 300 degrees was very poor.

As far as we can determine, the high temperature compounds which were presented to us for testing, didn't appear to have any more merit than the standard compounds we were testing. They seemed to have the same characteristics and in the general appearance of the seal. We did not run any impulse tests on that set up.

I guess that's about all the data I have to present at this time. Maybe I can think of more to add during the course of the discussion.

MR. CHATTLER: We will now hear from Mr. Detweiller of Lockheed Aircraft Corporation.

MR. DETWEILLER, LOCKHEED: Things I have to say are in regard to the early stages of the test program which we have embarked on for the testing of packings for use of the elevated temperatures.

This setup that Ralph Middleton mentioned, where we have the gland installation on a straight shaft, operating the shaft through a 1" stroke we have been running at 400 degrees F, using standard packings, the more recent test being with teflon back-up rings.

The last test completed shows evidence that our procedure was not adequate inasmuch as we have been running at the elevated temperature. This is wrong for two reasons: One is that we found that after having run large numbers of cycles at the elevated temperature, any time we reduced the temperature to say room temperature, 70 or 80 degrees, we immediately had leakage, while after warming up again, just before 100 degrees, the leakage would discontinue.

Naturally, a package is not very good if it seals only when it is hot. That would indicate that any test program that you embark on to test synthetic or rubber-like packings would require a temperature range--that is, you don't run a large number at any one cycle, but periodically, throughout the duration of the test, you have to decrease the temperature to see where the leakage will develop.

The other thing is that the thermal expansion of the rubber seems to be providing a characteristic which is to be considered. The volume of the "O" ring in its room temperature situation is less than the volume of the groove. It is less than 100 percent occupation; on the order of 80 percent, or something like that. After having run 28,000 cycles, when we take the packing out it's very apparent that it had 100 percent occupation or greater than 100 percent.

Inasmuch as the teflon rings--we had teflon on both sides of the ring, in other words, pressure side and external side--we had as much destruction on the teflon as we did without the teflon. We were getting to where we had more than 100 percent occupation.

The only information we have been able to find on the expansion of rubber would indicate that it's in the neighborhood of as much as 12 times that of aluminum which, of course, then indicates the higher the temperature you go to the more critical the occupation might be.

If you have to decide whether you want to provide more grooved volume in order to accept the full volume of high temperatures, or whether you want to try somehow to keep the ring from extruding while you're providing more than 100 percent occupation. I'm not sure which is the right direction to go, but at lease that needs to be considered. That's probably one reason why we provided a good seal at high temperature; we didn't have a seal at low temperature. We got more than 100 percent occupation and it started to seal at that point.

MR. CHATTLER: Any questions?

MR. KELLER: I'd just like to add to that. Instead of considering that in

terms of temperature, there's a lot of swell in any elastic being in a fluid.

We noticed where we had "O" rings at high temperature they have swelled. Take them out and set them aside and they would go down. Wouldn't you say that would be true, Bart?

BART: That's true.

MR. DETWEILLER: While these first tests we ran were with leather back-up rings, the leather rings got hard and broke the "O" ring. After 28,000 cycles, using teflon, they were almost like new. I happen to have them in my briefcase if anybody wants to see them. That's when they were run with teflon. Apparently there is something that happens at 400 degrees.

MR. CHATTLER: Any other questions?

We'll go to Glenn L. Martin's experiences. Have you run any tests at all at high temperature?

MR. COOKE: No. Leo, we haven't had any specific high temperature tests.

MR. CHATTLER: Okay, nothing from Glenn L. Martin. How about McDonnell?

MR. IRWIN: No, we haven't run any high temperature tests either, Leo.

MR. CHATTLER: Next is Mr. Oppenheim of North American Aviation, Inglewood.

MR. OPPENHEIM, NORTH AMERICAN: ([illegible] Appendix 1) We have here a summary of all high temperature evaluations to date. [illegible]r, there isn't enough to go around. I would like the services to each get one, and [illegible]ne to each manufacturer here.

In general, the summary clarifies past experiences up to 250 degrees F and the present trend and also future trends. The data included in the report is a summary of North American findings and the services and contributions from other manufacturers. In the lab we have run screening tests on various fluids with the 5606 and the diester fluid, ML 3908, the Cal. Research product, and the OS45-1 from Monsanto. We screen these fluids on a pump analysis that was run at 300 degrees F. These pumps were built to give system pressure and also flow.

Just a quick rundown on the total number of hours that each pump ran with the various types of fluids: With the MIL-5606, we had 22.2 hours of total testing time after 300 degrees F. This failed to maintain system pressure. The other pump ran likewise, 22.2 hours at the same temperature and also failed to maintain the system pressure.

On the ML 2029 fluid, which is the diester base fluid, we had a pump failure after 6 and 7.1 hours at 300 degrees. MLO 4938 fluid, one pump ran 40.5 hours.

This information is on Page 10. Some of the problems encountered here were piston bore problems. We also had packing difficulties and lack of pump and fluid conditions, and we had thermo difficulties causing the binding of moving elements as well as fleecing of the pistons in the cylinder.

From this analysis we screen our future test fluid, which is OS45-1. For our future work we have been going along with this work. However, from other records, there is a development of MLO 8200 which is a California Research product. It's a new product, just developed.

MR. CHATTLER: Lt. King, is your ML 8200 the same as the Cal. number?

LT. KING: Cal. Research developed them all under the Air Force. MLO means Materials Laboratory Order. [illegible]23 was the first group developed from a C6-C8 silicate. There was a choice of C6-C8 ratio for the best viscosity characteristics. That material was thickened with a silicon which was later found not to be too compatible. Also some sludging was noted. To try to get away from this the attempt was made to toss what average oil men call soap in. There you have 6938. That did not prove successful because we had an inner action of the silicon and soap. That's the reason for the excessive corrosion.

About this time Mr. Keller developed a vapor phase oxidation phenomena or what have you. We felt that a flash point of 350 for an oil developed for 400 degrees maximum use was probably too low. But increasing the flash point, which is a crude measure of vapor, we would decrease the amount of material in the vapor phase and therefore decrease its susceptibility to oxidation.

In other words, to do that we had to go to a dimeta silicate. However, this 8200 is the final thing under a contract which you might have noted were in the Cal. Research report either C6 or C8. We have added to this a metal deactivator.

MR. OPPENHEIM: As far as the system of components, we have a little information as to that, and that is on Page 11.

MEMBER: What kind of pump is that?

MR. OPPENHEIM: Vickers 1503 constant delivery pump. It seems like the question mark is in the number of hours that a system or component can operate is determined by the "O" ring in the packing material. It seems that most of your "O" rings and packings will take a permanent set after 5 hours of actual operation or soaking at your higher temperatures.

After that is mostly a direct correlation between wear characteristics as to when the "O" ring will fail. We have tried various "O" rings--the standard "O" ring and the selastic material. However, the selastics are not compatible with OS45-1. There is a hundred percent swell in that instant.

Here is the picture of the "O" ring before and after it was immersed in OS45 for a 24-hour period. However, this is not the case with your standard packing. There is difficulty with your hose assemblies and to date we have not too conclusive information on the ability of present hoses to withstand 50 hours of 300 degree operation which we are attempting at present to standardize.

The leather back-up rings will charr after approximately 5 hours of operation at 300 degrees F and will crystalize and score the actuating cylinders. Teflon back-ups work satisfactorily. However, there was evidence of cold flowing and a slight feathering condition.

We had a few failures in our types of solenoid coils. We used the standard units and their solenoid coils did burn out after a period of testing at 300 degrees F and changed it to a Marvista type solenoid and it has worked satisfactorily up to 300 hours F.

The filter will be satisfactory after 2500 hours of operation. We have tried the Permanent Corporation's special metal filter and it is very satisfactory at 300 degrees F.

At present, we are attempting to evaluate a variable volume pump which is a Vickers, 6 gallon type.

MR. CHATTLER: This latter test you spoke about was 5606?

MR. OPPENHEIM: That was OS45 with all 3 types of fluid. At present, this variable volume pump, which is the 3207 standard pump, we have run the system for 20 hours to date and the volumetric efficiency decreased from 98 percent to 93 percent.

The internal leakage across the drive and load cylinder was approximately 15 drops after 20 hours. The cycling rate was 7 cycles per minute.

This operation is an intermittent operation, so to speak, that we start anew each morning and warm up rapidly from an ambient condition from around 65 degrees and we have a temperature rise 2-1/2 degrees per minute in our chamber. The actual testing time per day when would be 5 hours at 300 degrees.

To date we had some experience with the spring tensions losing their durability and also a loss of system pressure, especially in the Vickers type relief valves. I think that's about all.

MR. CHATTLER: Any questions?

MR. LANG: Is this OS45 you use that which Monsanto calls Skydrol?

MR. OPPENHEIM: No, it's not Skydrol, but it's a later development.

MR. LANG: But you use the standard type "O" ring?

MR. OPPENHEIM: Yes.

DR. KLAUS, PENN STATE: How do you heat the fluid in the pump?

MR. OPPENHEIM: We heat it through a relief valve system. We have jackets around the pumps and the case temperature was approximately 300 degrees and the oil inlet was minus 2 degrees.

DR. KLAUS: In looking at these data, this PLR 3039, you mentioned that's not a high diester. That is the poorest diester you could pick, which falls apart thermally at about 400 degrees. It was never intended for high temperatures. It was intended for 250 or 300, in which area it is apparently working fine. This type you are looking for is MIL-7808, the jet inlet oil spec, which gives you another 150 degrees. Diesters of that sort we've run in our test stand for 12 or 15 hours at 500 to 525 degrees F, and a total of 40 hours above 350 degrees F without any appreciable deterioration in the oil. It's not currently an aircraft type pump.

That happens to be a little Vickers Vane Pump which is manufactured for the General Motors Corporation and is used as a power steering unit. You probably have them in your Chevrolet if you have power steering in the 1954 model. But General Motors and Vickers rated it at 500 degrees. We ran it with a fluid and as I said, we have 40 hours operating time. It's an interesting pump in that all the varying members are steel.

The vanes are located against the cam ring by centrifugal force. The bushings are loaded by hydraulic pressure, so differential expansion problems are nil.

I think there's some misunderstanding on 3039. A number of tests have been run in industry on diester type of fluids and the reason for that was to catch low temperature performance.

Let me mention, as far as I know, 3039 is obsolete. Fluids meeting this spec 6387 are now not being produced from secondary alcohols, but they do meet the low temperature properties. That is, you can get the high temperature properties of the 7808 and still be under the low temperatures.

LT. KING: I'm recovering from Doug Moreton's cigar, but getting back to 3039, and tests in general on the pump, 3039 was designed for use on the standard alternator drive. I'm a hacker when it comes to mechanics, but I believe that was a combined hydraulic motor-governer affair. You hydraulic engineers know a lot more than I do about it, but we have even more than 500 hours in service out of 3039 and in lubricity it was all right.

Right now we're studying some of the material for the reclamation program. Some of that fluid used 500 hours was examined by Penn State under the original work of putting it in the alternator drive. At the end of 500 hours it still looked good.

My question is, are we still trying to measure lubricity on pumps designed at 160?

MR. CHATTLER: Let's answer that later on, when we talk about pumps.

Tomorrow morning we are going to cover the components, materials, fluids, etc., and for that discussion you will all have had the benefit of the present experiences of the industry, so we will be able to finalize our thinking about what we should be doing in the future. That's why I arranged the program in this manner.

For the remainder of the afternoon I want to finish the presentation of the company experiences in high temperature test work. Therefore, during the course of the afternoon, don't get concerned if some point goes by that you think you ought to have your say on. You will have time to do that tomorrow.

We finished North American, Inglewood. The next company is Republic Aviation.

MR. FERENS, REPUBLIC AVIATION: We have been working on hydraulic fluids and components materials for some future airplanes. However, we do not have extensive data to report on as yet. We have, however, run a two hundred hour 300 degrees F hydraulic pump test on New York Air Brake pump satisfactorily through the two hundred-hour test on a Texaco diester type hydraulic fluid DL-122-3.

We have also run compatibility tests on various synthetic rubbers and other materials used in the hydraulic system on rubber, plus Monsanto OS-45 and this Texas fluid and some other diester material. However, we are setting up a thermo chamber for testing a typical hydraulic system for testing all the components at elevated temperatures. This equipment is nearing completion, and we hope to start testing various fluids and components in the near future, such things as performance of pumps, coatings, various coating compounds, other types of hydraulic seals, filter elements, electrical units, pressure switches, cylinders themselves--the full assembly inside of the cylinders-- and all of those types of problems.

We hope to start testing on this phase of the program the next month or so.

MR. POLLARD, REPUBLIC AVIATION: This is the spring material temperature data. It is taken from a paper given to the ASME by Harold C.R. Carlson, in one of a series of sessions they held in New York last fall covering all phases of spring design:

"Permissible Elevated Temperatures for springs. Loss of load at these temperatures is less than 5% in 48 hours.

Springs used at high temperatures exert less load and have larger deflections under load than at room temperature. The modulus of elasticity, which determines deflection, is reduced with increased temperatures thereby causing greater deflection under load. The torsional modulus for steel may be 11,200,000 at room temperature, but it will drop to 10,600,000 at 400 degrees F. and will be only 10,000,000 at 800 degrees F. The elastic limit also reduces in value, thereby lowering the permissible working stress.

RECOMMENDATIONS: Design stresses should be as low as possible for all springs used at elevated temperatures. Corrosive conditions usually occur with high temperatures--especially with steam--and may require using a corrosion resistant material. Allow for 5% loss of load. The temperatures listed may be increased 20 degrees to 40 degrees, but the loss of load may be nearer 10%. The materials are in the heat treated or spring temper condition.

SPRING MATERIAL	PERMISSIBLE ELEVATED TEMPERATURE
Brass Spring Wire	150°F.
Phosphor Bronze	225°F.
Music Wire	250°F.
Beryllium Copper	300°F.
Hard Drawn Steel Wire	325°F.
Carbon Spring Steels	375°F.
Alloy Spring Steels	400°F.
Monel	425°F.
K-Monel	450°F.
Z-Nickel Type B	500°F.
Stainless Steel 18-8	550°F.
Stainless Chromium 431	600°F.
Inconel	700°F.
High Speed Steel	775°F.
Inconel-X	850°F.
Chrome-Moly-Vanadium	900°F.
Cobenium, Elgiloy	1000°F."

MR. CHATTLER: Any questions?

MR. KELLER: What was the New York Air Brake pump used in the test?

MR. FERENS: This is a 66WA300. It's a standard pump, except with modifications for the damping portion of it to eliminate some chatter, the higher temperatures to bring about low viscosity. The temperature was kept at 300 degrees. It was a

two-hundred hour test that went up from 150 degrees on up to 300 degrees over a period of a hundred hours of operation, followed by a hundred hours at 300 degrees, at 3000-lb pressure and full flow.

DR. KLAUS: Do you know what the viscosity of the Texas fluid was that you mentioned?

MR. FERENS: About 3.8 centistokes.

MR. SHARP: Did you notice any difference in the running of the pump when you got to 100 degrees or higher, say, in the sound of it?

MR. FERENS: Actually the pump was run at New York Air Brake, and they reported--

MR. SHARP: You didn't observe the operation?

MR. FERENS: I knew that it was operating.

MR. SHARP: Do you know what the aileron pressure was?

MR. FERENS: Slight suction on the aileron.

MR. WEINER, NORTH AMERICAN: What was the code designation of the Texas fluid?

MR. FERENS: TL-2293. They added an inhibitor to it and called it 2364. 2293 is the same as the 2364 that you may have had, without the oxidation inhibitor.

MR. POLLARD: The fellows at New York Air Brake reported that, if anything, the pump ran smoother and quieter with this fluid--and at the temperatures around 250 degrees and 300 degrees--than before.

MR. CHATTLER: Did you give the viscosity temperature extremes on that fluid?

MR. FERENS: It's about 5000 centistokes @ -40 degrees F.

MR. SHARP: Was the response of this pump that you had at room temperature?

MR. FERENS: They didn't take the response time at New York Air Brake.

MR. KELLER: We have had some of this fluid, and we noticed that upon storage acid crystals formed that came out of the fluid and formed on the bottom of the container. Have you noticed anything of this nature with the fluid?

MR. FERENS: No, we haven't yet. We may have, with the material with the inhibitor in it.

MR. KELLER: If you had the material with the inhibitor in it? Maybe some of the inhibitor came out of it.

QUESTION: Was it green color?

MR. FERENS: Right.

QUESTION: You say it is an acid?

MR. FERENS: That's what we are told.

MR. WEINER: It's crystals, not acid.

MR. CHATTLER: Our next company is North American, Columbus. Do you have anything, Bob?

MR. KIBELE, NORTH AMERICAN AVIATION, COLUMBUS: No, I have nothing to add.

MR. CHATTLER: Then we have Convair.

<u>MR. KLEVEN, CONVAIR, FORT WORTH</u>: Our attention is in the starting phases.

We have done a little work on fluid and packings. We essentially have no results except preliminary screening until we get readings on a test which is now complete. We expect to get some more results fairly soon.

We have been testing fabrication of three or four half-hard resistant steel tubings in half-inch and three-quarter inch diameters, the purpose there to try to regain some of the weight due to reduced strength at high temperature. We found that in these sizes the tubings will flare satisfactorily; the bending has been questionable, but we have been able to get bends down to the standard minimum. We believe heavier tools are needed to accomplish the bends satisfactorily, and we've got to correlate the results we have so far with the minimum possible or allowable elongation, as against the 12 or 15 percent that the material we are testing actually exhibits. The minimum allowed was 7 percent.

We checked some felt wipers, Types 5 and 7 @ 350 degrees F. When they were soaked in MIL-O-5606 fluid up to nine hours, despite yellowing, the felts were satisfactory for the purpose to retain the absorbency, and there was no noticeable impairment.

To test the usability of AN818 nuts with steel tubing 350 degrees F, we've only got some partial results which were mainly aimed at checking the predictability. We have been able to correlate the fact of initial stress as against that stress built up--rather, the initial torque--if it results in excessive tension in the nut due to the friction not being what we expect, could at the higher temperature mean that the stress is excessive and means cycling of the stress at a high value, due to failure due to fatigue.

I have some comments and recommendations that I would like to make, and the primary one here is with respect to the temperature objective of our development programs here, overall Industry and Service wide. For our purposes, we found that 350 degrees will do the job, by tailoring the system to that temperature.

During the period of about the past year, despite considerable development activity, there has apparently been little progress toward attainment of elastomer packing materials suitable for application in the -65 to 400 degrees F temperature range. WADC has agreed with Convair that the up to 350 degrees F range represents a fairly well-defined class of service for urgent near future needs, since requirements beyond this are generally for levels so much higher as to constitute a super high temperature class. Since present Convair needs also are for -65 to 350 degrees F system (fluid) operating temperatures, it is recommended that, as an objective for standardization and coordinated development, a class be established for this range. The 350 degrees F goal should supplant 400 degrees F or higher values for current major efforts for the following reasons:

1. It appears that successful attainment of 400 degrees F continuous duty for all necessary hydraulic elements will be reached only with great difficulty, particularly in the case of packings, hose and pumps. Fair success at 300 degrees F and limited operability at 350 degrees F seems to indicate that with reasonable progress 350 degrees F can be reached in the near future in time for use on piloted aircraft projects now in work.

2. Lack of early standards for high temperature elements encourages adoption of individual design solutions and thereby delays realization of the benefits of standardization. Existence of standards for some value of elevated temperature will encourage efforts to design aircraft hydraulic systems for such a limit. The operating temperature used for design is usually subject to some degree of selection wherein peak ambient temperature is the floor value. An objective of 350 degrees F will promote earlier standards.

3. A temperature of 350 degrees F provides a differential over ambient suitable for ram air fluid cooling and static system exposure in most piloted aircraft flying speeds now believed in work.

4. Formal adoption of a 350 degrees F limit should greatly increase the chances of success for this value. The possibility of soon obtaining 350 degrees F elements as a by-product of working for higher temperatures is not good, since lines of investigation will probably not be adequately explored unless there is potential for the higher temperature.

5. A more attainable goal, such at 350 degrees F could be an inducement to greater independent efforts by commercial suppliers. Dissemination of information emphasizing a particular objective might also be very useful in overcoming present supplier reluctance which seems to be caused severally by confusion, pessimism with regard to technical success and uncertainty of commercial value in view of application variations.

6. Concentration of effort increases possibilities of success.

7. Attainment of satisfactory continuous duty equipment for 350 degrees F would probably permit applications for higher temperatures where endurance is limited. Missiles are a representative case.

8. Establishment of a temperature class to 350 degrees F does not exclude work for higher temperatures but places emphasis where need is great . If a near future realizeable limit is not set it may be found that the substan al aircraft performance advance possible with 350 degrees F will be in postponement indefinitely for the purpose of developing hydraulic elements to some ultimate high temperature capability.

9. If during 350 degrees development, leads are found which promise capability for higher temperatures, the periodic Services-Industry review will enable redirection of the program if conditions warrant.

MR. CHATTLER: Any questions?

We will now have Mr. Sharp of Convair, San Diego.

MR. SHARP: Mr. Chattler, we don't have a great deal of high-temperature experience, because we have been trying to build current airplanes to 160 degrees F specification limit. All our efforts have been directed to holding the line. How we did it, I'll have more to say about in just a moment.

One thing--it's a little bit of a sideline, as long as we are talking about 160 degrees experience--is a low pressure reservoir application of a low-range seal, 6-1/4" in diameter, with pressures ranging from zero to 60 psi. We found that if we put enough squeeze in the "O" ring to hold the pressures indicated over the range of temperatures, we got so much friction that we couldn't live with it. If we turned the "O" ring group down a little bit, we could hold her right under pressure, or at high pressure, but at least at low temperatures--that is, relatively high, 20 degrees or so, room temperature--caused quite a bit of leakage at low pressure.

The problem has been solved for the time being by going to a low squeeze "O" ring. This gives an indication that the same thing might be true over a spread of temperatures in a higher range, say 100 degrees to 300 degrees.

The reason I was asking about pumps a few minutes ago--we have some of the very low serial number New York Air Brake three-gallon pumps, and on MIL-0-56-6 they have a tendency to pound as soon as the temperature reaches 200 degrees. We don't know what effect this has on pump life, because we don't let it go on very long. We haven't worn a pump out yet, but when you hear something pounding the way these do, you become apprehensive as to the future of the equipment and shut it off.

MR. CHATTLER: You had WF-300?

MR. SHARP: No, this is the 66 type.

I'm glad you asked me. That reminds me we are operating that at 30 psi pressure, suction pressure, so I don't believe that is a cavitation problem. It just seems to be when the temperature reading goes up, the pumps start to get noisy, in the new type of positive pistons.

Is that your question?

MR. CHATTLER: Yes.

MR. SHARP: 66 is the positive loading; 76 is spring loaded.

Most of our ground tests--we have learned to see how long it would take to

pass 160 degrees F without any cooling on the different types of cooling, in an effort to hold the line in the specifications. Ground test on an actual airplane--it took five minutes without cooling to pass 160 degrees in normal use of the controls. The test run for another model, it took 15 minutes. On the actual airplane the curve is so steep that I doubt if it would become aspirated at 350 or 400 degrees. It's going right on up, apparently. Therefore, some kind of cooling is imperative, and I mention this because I heard some comments this morning which led me to believe that people think that fuel cooling is a good answer. They said, "We don't have the problem now, but we can always go to fuel cooling." We have found, much to our sorrow, that this is not a good answer. The engine people are quite critical over high temperatures in the fuel system. What's more, the pumps won't pump a mixture of vapor and fuel. You don't have to add much heat from the hydraulic system to run this thing out of sight.

Ram air is also out of the question, as most of you know, on high speed aircraft, so we are going to have to find some way of increasing the temperature limits on our oil, or else expend a lot of power refrigerating it.

For immediate suggestions, I have only one, Leo, and that is to make it legal to exceed 160 degrees as soon as possible.

MR. CHATTLER: It is legal to exceed 160 degrees F, see 5440-A.

Grumman Aircraft, do you have anything?

MR. WEISSKOPF: We have nothing on aircraft directl. . We did some work on missiles, which John Roukis will report on.

MR. ROUKIS, GRUMMAN AIRCRAFT: We ran two tests, actually: One a short-time; another one a little longer. One of them about fifty minutes an[illegible] minutes at about 350 degrees F; another test for about twenty to twenty-five hours

The first test was just to find out the characteristics of the system and find out what temperature it would stabilize at, at 350 degrees F. The system was New York Air Brake pump. In the first case, it was short-time, 66WB350 pump, and the fluid was Yukon LB300X. The second case, the twenty to twenty-five hours-plus, was made in conjunction with an actuator or response-test, hydraulic servo response test, and it was a 57WB300 pump. On one of these tests there were no detrimental effects due to operation under these conditions found. As I understand it--I didn't conduct the test myself--the units were not inspected thoroughly but merely visually at the end to see if there was anything wrong. There was nothing wrong, so it didn't go farther with the inspection.

There were no detrimental effects, by the way, on the AN-6227 "O" rings that we used in the system. That's about all I have, except that this Yukon is an oil about a hundred degrees higher viscosity curve than ordinary MIL-O-5606. At 300 degrees it had 5 centistokes viscosity. The application was actually, as I understand it, determined mostly for lubrication properties, using that oil to lubricate the gear case outside the hydraulic system, so I am not going to justify the use of that oil as an organic solvent.

MR. CHATTLER: Any questions?

Mr. Bremer, do you have any information?

MR. BREMER, BOEING AIRPLANE COMPANY: (See Appendix 2) I have a limited amount of test data here I would like to present.

To start with, our test facilities at present amount to a small hot-box, which we heat. We are planning to set up a larger oven which will have a top temperature limit of 600 degrees, very shortly. The primary object of our lab testing to date is to learn the limitations of existing seals and certain special seals, both Boeing-designed and outside-purchased seals, to learn the limitations of hydraulic system components, such as filters, valves, sonar valves, and maintain a log on the pumps we use for running these tests.

The pumps are probably the most expensive part of running the hot tests, and I have been very interested in hearing the comments from the others regarding pumps, particularly this one which was mentioned that ran at 550 degrees for 40 hours. It

appears that it is necessary to keep most of these mock-ups as simple as possible, in order to avoid breakdowns of components and hold up the entire test. So we have confined our system to a pump, ran it to actuator cylinders and mechanically-operated valves.

We also maintain a log of tubing and pitting failures.

To date all of our testing has been done with MIL-0-5606 oil, in a temperature range to 250 degrees. We have used only New York Air Brake pumps to date, 67B, 67W and the 66W. In the future we plan to use the Monsanto OS-45 oil.

We have the series of tests broken down into logs of Tests 1 to 7. I don't know whether I should take time to describe these individually or not.

MR. CHATTLER: Can you just review them briefly?

MR. BREMER: All right.

Primarily on seals, we have been using teflon in combination with "O" rings, either teflon cut strips or teflon surrounding the "O" ring, and the "O" ring then acts as a spring and a static seal.

The teflon seemed to be pretty good at temperatures up to 350 degrees. However, on some spot runs above that, we appeared to get considerable extrusion; the material is too soft.

Now to come back to cap strips for a minute. Various styles of cap strips have been tried. Those with square corners tend to extrude much worse than those with chamfer or radius into the corners. We found that the extrusion can be eliminated somewhat by having a thicker section on each end, as this sketch here would indicate.

Generally speaking, the purolator, or standard filter element, breaks down after about eight hours of running at 350 degrees. Apparently, it's a glue that secures the end caps to the element. We tried various of the selastic materials, 7180 "O" rings, under the cap strips and as you know, they foam excessively; but we figured protecting the oil ring with teflon gives a little better life. However, it did not prove to be true. Each of these tests is recorded with a current history. We maintain a log of the time in hours.

For instance, the temperature that you are running: Now, at the end of each day's run--we start at 8:00 o'clock, run through the day and run a cycle straight through during the cooling-off period which starts around 3:00 in the afternoon. This curve shows the firing up of the system in the morning and dropping off while cycling each afternoon. Thay way we attempt to simulate a six or seven-hour flight of aircraft.

Any questions?

MR. MAYHEW, REPUBLIC AVIATION: On this teflon cap strip, did you ever make any friction measurements?

MR. BREMER: Yes, we made friction measurements. I don't have the friction data with me. We're setting up a seal friction measuring device now, with which we record break-way as well as running friction.

MR. MAYHEW: Is that a long strip?

MR. BREMER: It is a machined strip. It is machined out. You might call it a piece of tubing that is cut off as great lengths.

MR. MAYHEW: Do you have any sizes on what you did?

MR. BREMER: All of our testing has been done on a cylinder which is 2" in diameter, the rod of which is 1". It's a double-ended rod, so we have balanced forces.

MR. MAYHEW: Mr. Sharp went into this question of having excessive friction in reservoir application, and I have something quite similar to it. I have a very large-size "O" ring, and I planned on using the material on top to cut down on the friction. That's why I was interested in the size.

MR. BREMER: With a non-standard groove; that is, a groove that is deeper than is called for in the spec, you would cut down on friction; and you would also cut the "O" ring to eliminate any possibility of having such failure.

MR. WEISSKOPF: Did you run any leakage checks with that on cap strips?

MR. BREMER: Yes, continuously, leakage checks were made. I believe it is better.

MR. STRAUS, WADC: We have done quite a bit of work in that particular field.

MR. BREMER: We have been able to stretch the Teflon over the gland and under the "O" rings. We have also been able to compress the cap and put it onto a rod into a rod gland.

MR. STRAUS: In a rod gland it's all right, but in a piston I know we have had a great deal of difficulty, especially where your cylinder bars are always chamfered for installation purposes. They require normal "O" rings, but to try to get that cap strip in there and get it in right is a pretty tough proposition.

MR. BREMER: When chamfer is cut down we've had better success.

MR. STRAUS: I'm thinking about on a production basis.

MR. BREMER: It is more difficult than "O" ring, granted.

MR. MIDDLETON: I would like to see a little sketch, maybe, on the board. I am confused as to what the cap strip is.

MR. BREMER: (Drawing on board) This is one variety we have tried. Just a straight--this is the centerline of a piston--a straight cap strip. Now, then, this is the first version we tried. Then we came down to some reinforcement on each side and added chamfers to the corners. The original type--we got excessive extrusion at the elevated temperatures. This type, the extrusion was kept to a minimum, and our friction characteristics ran pretty much the same. (See Appendix 2)

MR. DETWEILLER: How thick is that cap strip?

MR. BREMER: They vary in thickness; for a 2" size, from .040 to 080" thickness.

MR. DETWEILLER: Can you stretch that over the gland?

MR. BREMER: That's right. This is the end of the piston, and this is the cap strip, which can be stretched over this gland, and over into the groove.

MR. DETWEILLER: Do you have drawings on your cap strips showing what your angles are, to put the legs on the ends?

MR. BREMER: Yes.

MR. CHATTLER: This will all be in the report of the meeting, so you will get it. (See Appendix 2)

Any other questions?

MR. MAYHEW: Can you tell me who makes that? Did you make that yourself?

MR. BREMER: These have all been machined by Boeing. However, there are other companies that do a lot of subcontract work that machine special.

MR. CHATTLER: Any other questions?

The next company is Chance Vought Aircraft. Mr. Ludwig.

<u>MR. LUDWIG, CHANCE VOUGHT AIRCRAFT</u>: For some time now, we have been taking components that have successfully passed the specification test at 10,000 cycles at 160 degrees, and you might say, re-qualifying, running 15,000 cycles at 175 degrees

and 5,000 cycles at 250 degrees. In general, they will all do this, but the packing life is pretty short; but one change of packing seems to get them through. Doing 15,000 cycles at 175 degrees and 5,000 at 200 degrees seems to be no strain at all.

We bought some British valves just to test--that might be of interest--ran them 20,000 cycles at 175 degrees turned right around and ran them 20,000 more at 200 degrees, and didn't have any trouble at all. That's about the extent of it.

MR. MARTIN, DOUGLAS AIRCRAFT: Were they equipped with "O" rings or square sections?

MR. LUDWIG: "O" rings.

MR. CHATTLER: Any other questions?

MR. BREMER: I had a couple of questions here that I would like to ask. One is regarding whether or not anyone has run metal seal.

MR. CHATTLER: We will probably get into that tomorrow.

MR. GREEN, WADC: I would like to ask what kind of components Chance Vought tested.

MR. LUDWIG: These are cylinders, valves, the whole works.

MR. CHATTLER: Can you get us specific information?

MR. LUDWIG: Well, it's rather difficult.

MR. CHATTLER: What did you do, just run the tests and throw away the information?

MR. LUDWIG: This elevated temperature data has been mostly for our own interest. In other words, we qualify the equipment to the spec, and then our test-job people got a little bit enthused over this high-temperature deal, so they have been taking components and on the side turning around and re-run them. We have submitted certain isolated units to you on the basis of this 175 degrees F 1500 cycle and 275 degrees F at 5,000 arresting gear cylinder, is the one I know of.

MR. CHATTLER: Would you please make a note and see if you have any test data? If you have, try to get it to me so we can put it in this report.

MR. LUDWIG: I know we have a test report on the starting valve.

MR. CHATTLER: Douglas, Santa Monica. Mr. Murphy?

MR. MURPHY, DOUALAS AIRCRAFT, SANTA MONICA: I will have Mr. Martin speak.

<u>MR. MARTIN, DOUGLAS AIRCRAFT, SANTA MONICA</u>: When we were introduced to this 300 degrees problem about five years ago by our engineering department, at that time we developed our laboratory to take care of 450 degrees; systems, components, and sub-systems. Since that time we have done considerable work at 300 degrees and at 450 degrees. I think Doug Moreton will report on most of the above 300 degrees work.

At 300 degrees, well, I haven't brought any specific test results on it, we had a lot of tests on cylinders, relief valves, hose, pumps, packings; and to briefly cover the field, we didn't experience a great deal of trouble at 300 degrees on any components but hose, a few springs, relief valves, and packings. I might add that accumulators, regulators and pumps were run at 250 degrees.

On the packings, we have since--well, about a year ago--undertaken a more intensive R&D program in conjunction with Wright Field, and I would like to define the limits of that work first and then generally cover the results of it.

Details of the work we have done on that are being prepared and will be distributed to your respective companies. There are probably some two thousand-and-some tests involved.

Specifically, this packing development program dealt with MIL-O-5606 oil, 300 degrees operating conditions, test procedures generally in accordance with

MIL-P-5516A; but I think there is a lot to be said about methods for testing packings and most of this has been covered in the report that is coming out.

The analysis of the results is also vitally important. It's very easy to mistake a packing failure for a back-up failure, or vice versa. In connection with that, the earlier part of the program, we found there were very few packings on the market that would withstand a 300 degrees temperature, and their performance was very short, very limited--until we started using the Teflon. As I say, this work was intended primarily to find out what the limits of standards were; how far could MIL-O-5606 oil be used and still obtain packing compatibility--standard grooves, standard packing configurations. In that respect, we worked mostly with letters.

Then we started using the spiral Teflon, and found that, again, a certain amount of reproducibility in packing failure was lacking, since in some cases the Teflon would extrude, and in others it would not. Later in the program we found that by reducing diametric clearances, we could get Teflons to perform satisfactorily in each successive test. Now the packing that we were working with predominantly was 2-1/2" and called for diametric clearance of .002 to .007. We were operating at the outside, or .008. By reducing this diametric clearance to .005, we have had very good experience.

At the present time we are reviewing quite a bit of the work that was done in previous packings. Most of this is done, but we are reviewing it again at the reduced diametric clearances and our results to date indicate there are one or two packings that are compatible with MIL-O-5606 at 300 degrees. While I don't know exactly what the performance--or how the performance--of a packing at 300 degrees compares with service experience, or how it compares with a standard packing at 160 degrees, we rather expect it will have somewhat reduced service life.

The next phase of our program will be involved in determining whether the 300 degrees packings that we have will perform as satisfactorily at 160 degrees as standard packings perform at 160 degrees. If this is true, we feel that most of the standard packings as we know them today could be replaced with several of the high temperature compounds, and wind up with one or two packings that are good for the range -65 degrees to +300 degrees.

As for packings above 300 degrees, there is little that we have done--I think there is little that can be said right now, until somebody decides what sort of fluids we use over 300 degrees. Some of our experience, as Doug will report, indicates that standards are good on OS-45, and I think to define how good, you have to pretty well set down what the service requirements are--what is considered good.

Incidentally, it is interesting to note that we also have worked with the cap seal that Mr. Bremer pointed out a short while ago. We have had some experience with it, and that experience showed almost the same results that you obtained. We have since, however, introduced some metal back-ups, to prevent any extrusion of the Teflon, and these metal back-ups are not as unwieldy as you might think. They are manufactured from laminated shim stock--brass shim stock--and put a scarf cut on it, the same as the old cut Teflon had, so you can slip it over a piston head. It works fairly well.

MR. CHATTLER: Any questions?

The next company is Douglas, El Segundo. Do you have some information, John?

MR. BURNS, DOUGLAS AIRCRAFT, EL SEGUNDO: El Segundo is pretty well dependent on Santa Monica for high temperature range. We haven't gone to temperatures above the operating temperatures in our systems. At present, that is at the 200 degrees range.

MR. CHATTLER: We'll have Mr. Keller, of Downey next.

MR. KELLER: As you know, we have been working on this high temperature problem for somewhat better than three years now, and a good part of what we have done has already been reported. I think a large part of it was included in the minutes of the Lubrication Conference held at the Pentagon a year ago, November, and in the Lubrication Conference held at Wright Field last April; and in the papers given in New York last April, and in comments that were made at the various SAE meetings. I'll just cover a few of the more recent developments.

I was interested to note that on this Bell problem they had no one who dared let liquid oxygen cool. We just had made some tests with OS-45 in contact with liquid oxygen, because we have this problem, and we found--we poured two quarts of liquid oxygen into a hole and poured four ounces of OS-45-1 on top of it and put a C-1 strip on it and fired it off--and nothing happened. It was quite surprising.

Then we have a machine in which you put some liquid oxygen, then some test material. In this case we used OS-45--and we hit them with a hammer--and they tell me you can explode practically any organic compound with that. We ran ten runs, and out of the ten runs we got one rather weak explosion. It's quite astounding, because the day before we made these runs, the man whose responsibility this sort of thing had been, had assured me that the combination was equivalent to TNT.

We also had just finished making a test on a relief valve. We wanted a relief valve to operate up to 500 degrees F; as a matter of fact, from -65 degrees, if we could get it, to 500 degrees, and we got a relief valve from Pantex. We had just finished the test on that last Thursday, and you might be interested to hear that the change in packing pressure, the dynamic packing pressure from -65 degrees our packing pressure was 3450 psi, and at 500 degrees it was 3425 psi; and we had a--it might go up or down 10 psi, and of course the change could be just experimental error over that whole range. Really quite terrific.

We've done a lot of work in the way of seals. It seems to me the remarks made about the back-up rings and the type of fuel we've had have been equally as important with us, and we found that, for instance, we had trouble with Teflon like the other people did.

MR. KELLER: (See Figure I) This is a horrible example of what happens to a Teflon back-up ring at 350 degrees, after you work it a little bit. We had so many of these that this is just a very typical one, and nothing unusual at all. As the result of that, for anything above 350 degrees, we are not liable to consider the use of Teflon at all. It's a messy thing to handle, and we have found pieces of Teflon floating around inside the hydraulic system. Where you have delicate servo valves, you don't want to have a piece of Teflon floating around.

(See Figure II) This is what happens, again, with the Teflon at 350 degrees. This happens to be a neoprene-W seal in this particular picture, but we have had the same thing happen with the neo-M compounds and the standard "O" rings, and this is the sort of thing that gives us all sorts of fits when we try to operate at temperatures which are elevated to any particular degree. We just keep on having these.

We tried, as I mentioned at the recent SAE meeting, using some metallic back-up rings. Now these (See Figure IIA) are solid back-up rings, made out of aluminum bronze, and unfortunately they require the use of a split piston in order to utilize them; but using a neoprene-W seal, and OS-45-1, and using a seal test machine very similar to the one that is at WADC, operating a 1" stroke at 2 cycles per second--which is an extremely high-duty cycles--we operated for 100,000 cycles at 400 degrees with quite insignificant leakage, and a few small clouds of gas that we couldn't condense. We condensed most of the gas.

So we do have trouble with this particular configuration, because of the requirement for the split piston.

(See Figure III) We then tried making some spiral back-up rings out of aluminum bronze, and we found that we could machine those out of bar stock on a lathe without too much trouble; and we put these in the same testing machine at the same cycling rate and again operated these seals at 400 degrees for 100,000 cycles. That's a little over 14 hours, I recall, and the seal at the right in this case leaked 21 cc's in the 14 hours; and the seal at the left, which looks considerably more horrible, didn't leak a bit.

(See Figure IV) Now, this is a glass-loaded Teflon. We had heard great stories about what that would do, and we tried out the glass-loaded Teflon, but this particular test was made at 350 degrees and failed after 22,000 cycles. Again, this is a fairly typical failure of Teflon.

(See Figure V) Here we have the comparison of two rings, neoprene-W again. The one at the right has the spiral bronze back-up ring, and the one on the left has the spiral Teflon; and they operated at 450 degrees. Of course, we had 3000 psi between the seals. The one at the left failed at 33,000 cycles, and the one at the

right had given no difficulty whatsoever up to this time.

(See Figure VI) This particular seal test, again with neoprene-W oil ring: These seals operated for 19,600 cycles, which is about 2-1/2 hours, at 500 degrees F, before the "O" ring at the right failed. There apparently was no failure on the "O" ring at the left, and we feel that we have at long last with the use of these metallic back-up rings finally gotten to the point where we are testing "O" rings, rather than testing back-up rings.

I don't have a picture of it, but just before I left for here, we ran a test of the same sort of sealing setup with the neoprene-W seals at 520 degrees, and we got again--I think it was 18,000 cycles--roughly 2-1/2 hours again, at 520 degrees temperature. So this looks very encouraging as far as the seals are concerned. We are going to try doing away with rubber now and just use the metal. That would be the best thing, if we could work it.

MR. CHATTLER: Any questions?

MR. DETWEILLER: I have two questions: One, what was the wall thickness of the cylinder in which this thing operated; and the other is, what was your pressure cycle?

MR. KELLER: In this particular case we didn't hav a pressure cycle. We just maintained a 3,000 psi. We didn't try impulsing it. So what we have is probably representative of what you might get in a gland seal, rather than in a piston seal itself.

The wall thickness of the cylinder, I don't recall, Jim. We didn't take any particular pains to produce the cylinder. We just hacked one out of the particular bar stock we happend to have.

Incidentally, these back-up rings are machined to about a thousandth diametrical clearance; then we would wing them up and put them in, so that when they are in operation, we have practically no fap for the "O" ring to extrude into.

MR. MAYHEW: What was the material in the springs.

MR. KELLER: It was a steel body, with neoprene-W rings. It had three static rings and one dynamic ring and inconel spring. I don't know whether it was straight inconel, or inconel-X, but it was one of the inconels.

MR. BURNS: The spiral of aluminum bronze, could you give us a clearance picture?

MR. KELLER: We were operating with clearance of the cylinder to the bore, the same, I think; that is .005 to .007. We followed the MIL spec on both the gland and the clearance. What we are trying to do is do something that we possibly could retro-fit into equipment which we had already designed to MIL specs.

MR. BURNS: Physical dimensions, not including expansion, and pressure upsets?

MR. KELLER: We kept them to meet the MIL specs at normal dimensions.

MR. IRWIN: The basic thickness of thread is approximately the same as a spiral Teflon?

MR. KELLER: No, it's much thinner, because it's easier to cut this. We had about five laps on the spiral and left a gap of about half an inch, and then feathered the ends of the spiral in a full quarter of an inch, so the gap was practically non-existent, and what expansion we had merely tended to wrap the thing up a little more and perhaps gave us a better seal.

MR. IRWIN: After the spirals, do they end up with about the same net thickness?

MR. KELLER: The net thickness is the same. We designed this thing for a direct replacement. It may be that optimum design for this sort of outfit would take a different king of plan, but we had tried to achieve something which could make a retrofit.

MR. LUDWIG: I am interested in what the cylinder material is and the finish.

MR. KELLER: I don't recall. It was a steel cylinder. I suspect it was 4130, mainly because around our place they don't seem to know how to make anything out of anything else.

MR. MIDDLETON: How much clearance was there in the gland itself--how much drop was there at the bottom of this rod--between that and the bottom of the groove? Was it a close fit, a tight fit, or was it fairly loose?

MR. KELLER: I don't recall, Ralph. It was a fairly tight fit. Now, we could wing it up a little bit for installation purposes.

MR. MIDDLETON: Did you wind up the radius of the groove?

MR. KELLER: No, we didn't wind up the radius of the groove. We had a standard groove.

MR. STRAUS: What was the low temperature on the rubber compound?

MR. KELLER: We have operated these particular compounds at -20 degrees, I think that is the lowest we have played with them, Frank.

MR. BREMER: Were these 22,000 cycles put on continuously?

MR. KELLER: They were put on continuously, yes. All these tests were started and run until we had reached 100,000 cycles, or failure.

MR. CHATTLER: What is your low temperature requirement on that?

MR. KELLER: The specification still says -65 degrees. I don't believe it. We have a high temperature problem which we are going to meet, and if we can also meet low temperature specification requirements, we will do it. If we can't meet them, we will still try to meet the high temperature requirements, to get the job done.

MR. CHATTLER: The problem is the cold-soaking. Do you damage anything by cold-soaking it? I seem to remember back in the old days when we were dealing with -40 rings that when we put them down to -65, heating them up didn't make any difference, because they had been damaged already.

This completes the experiences of the airframe manufacturers.

Figure I - Typical Feathering of Teflon Back-up Ring at Elevated Temperatures

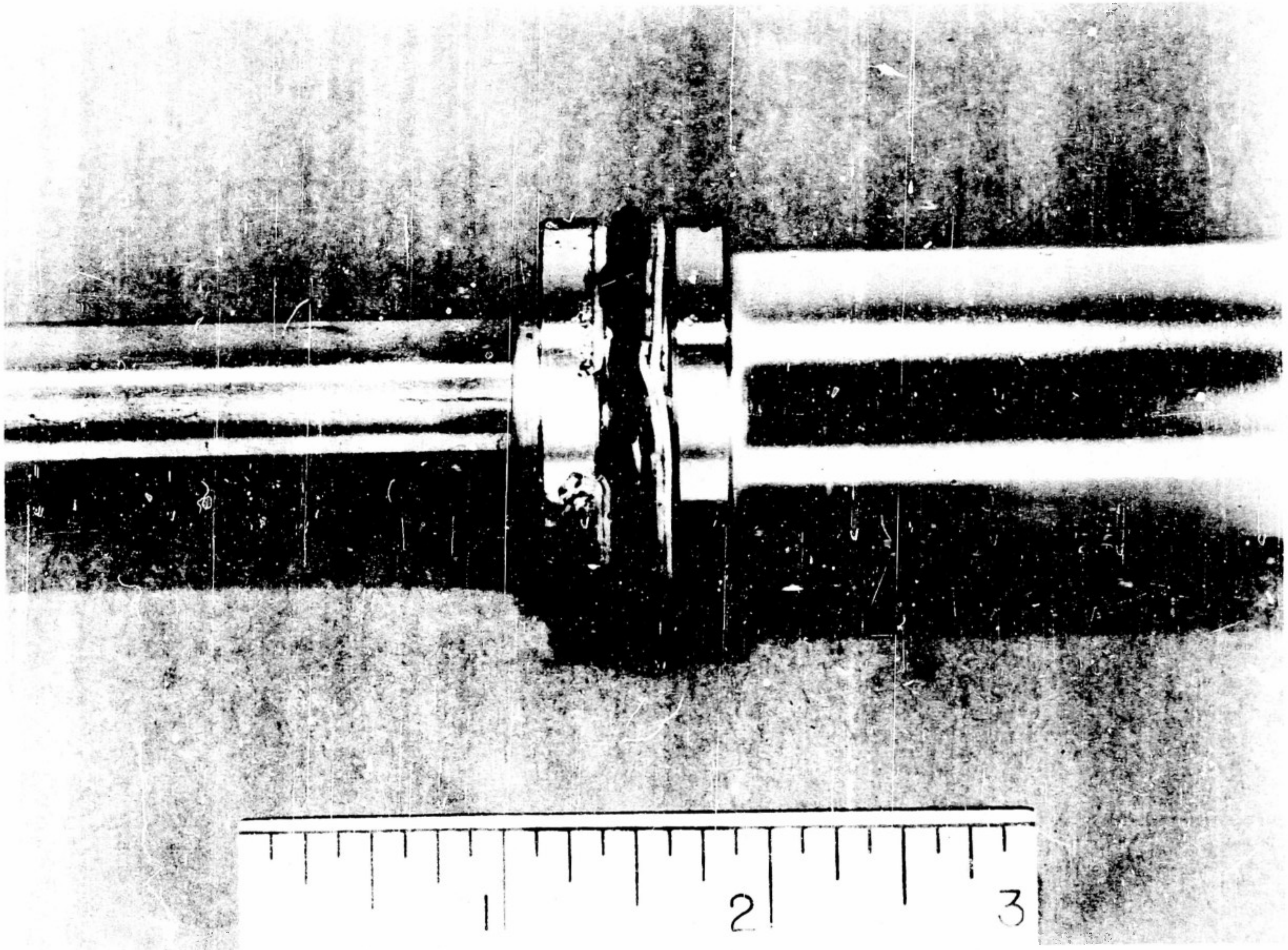

Figure II - Seal failure caused by breaking up of Teflon back-up ring. Neoprene "W" O-ring tested in OS-45-1 at 350°F. Failed after 61,000 cycles at 2 cps over 1-1/2" stroke under 3000 psi.

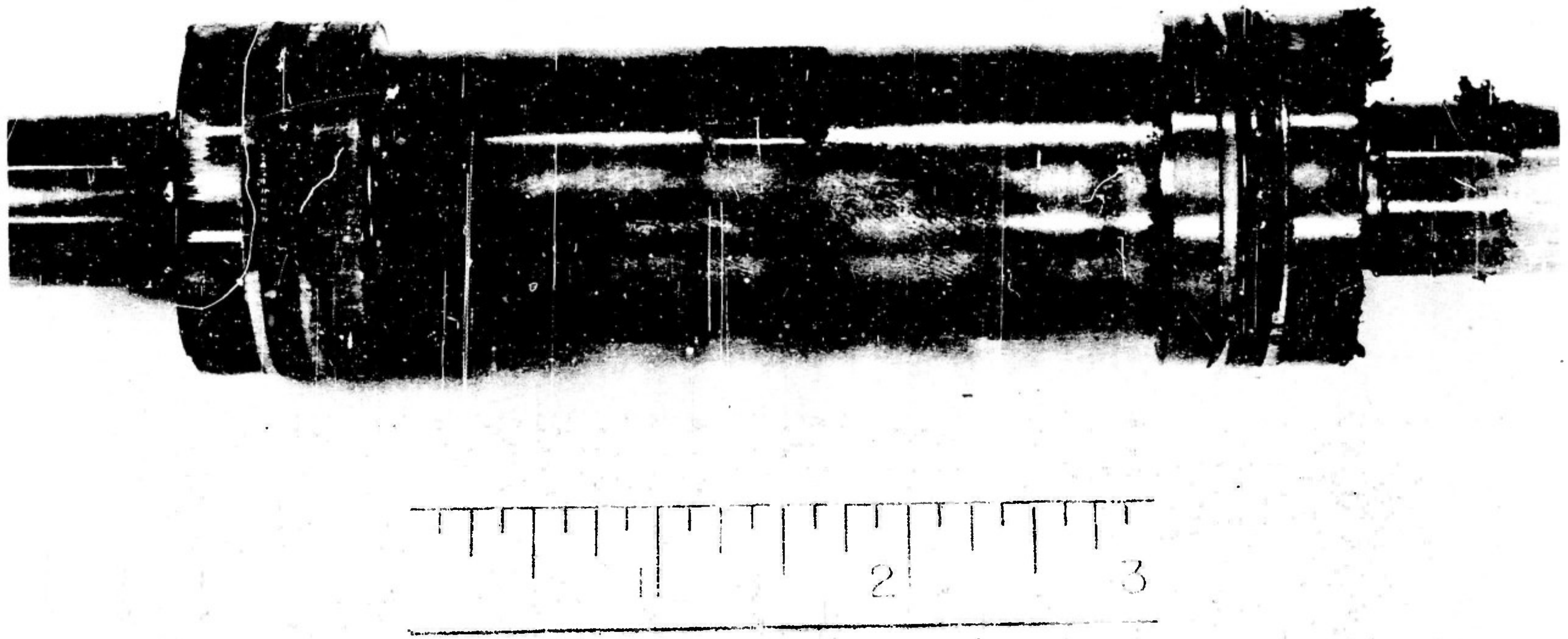

Figure IIA - Neoprene "W" O-rings. Solid bronze back-up rings
100,000 cycles at 400°F in OS-45-1 3000 psi
Leakage: Left End--None, Right End--10 cubic centimeters

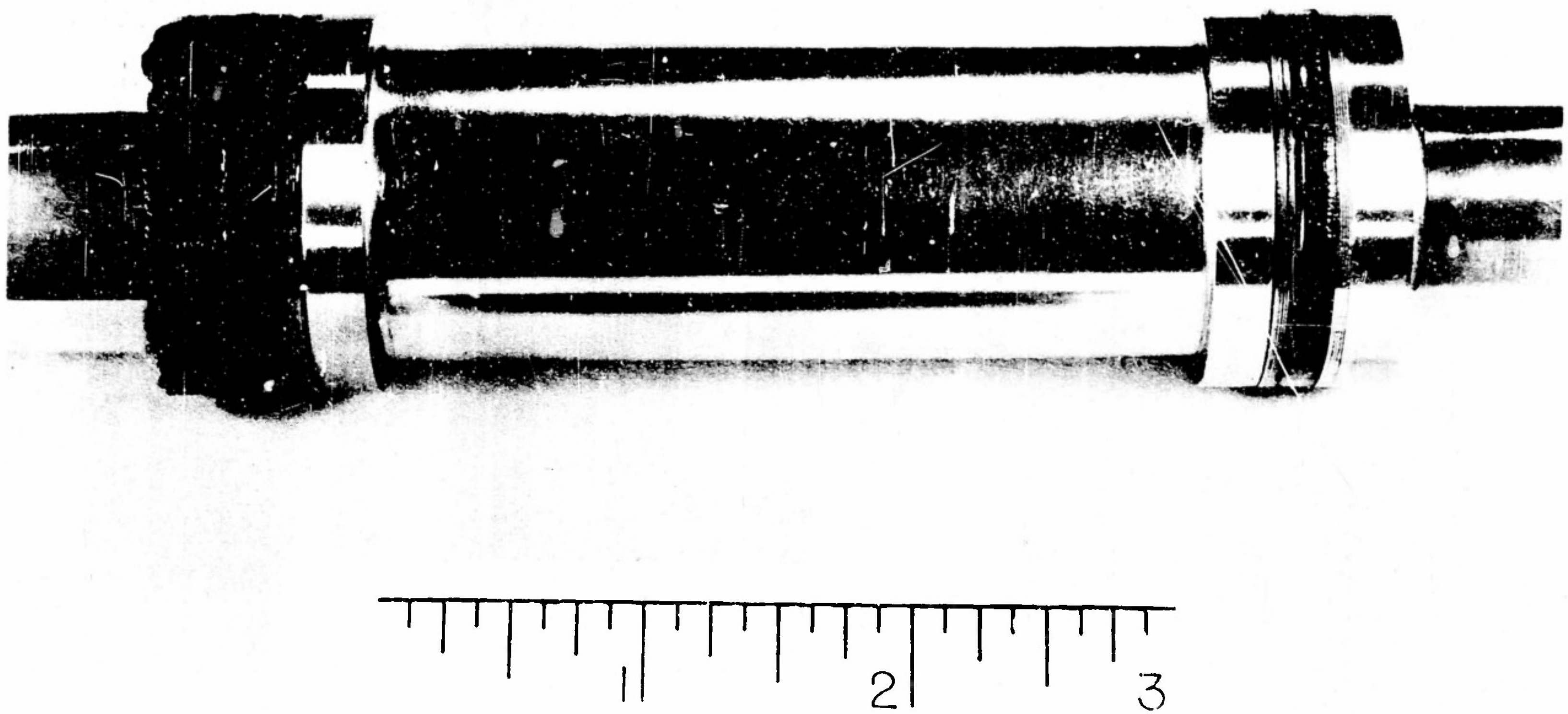

Figure III - Neoprene "W" O-rings. Spiral Bronze Back-up Rings
100,000 cycles at 400°F and 3000 psi
Leakage: Left End--None, Right End--21.5 cubic centimeters

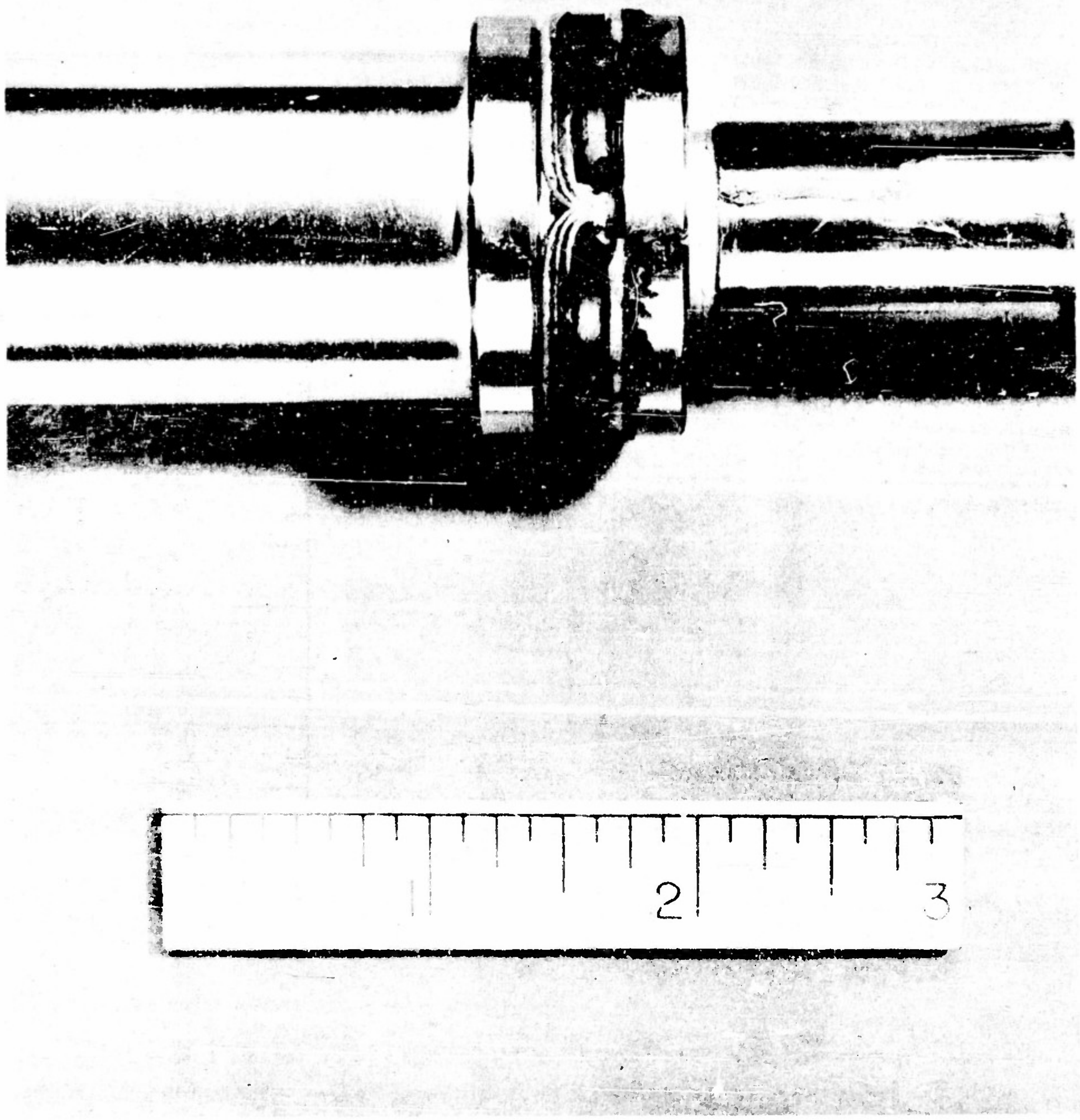

Figure IV - Neoprene "W" O-rings backed with glass loaded Teflon back-up rings. This seal failed after 22,000 cycles at 350°F. This is a typical "break-up" failure of the Teflon back-up ring.

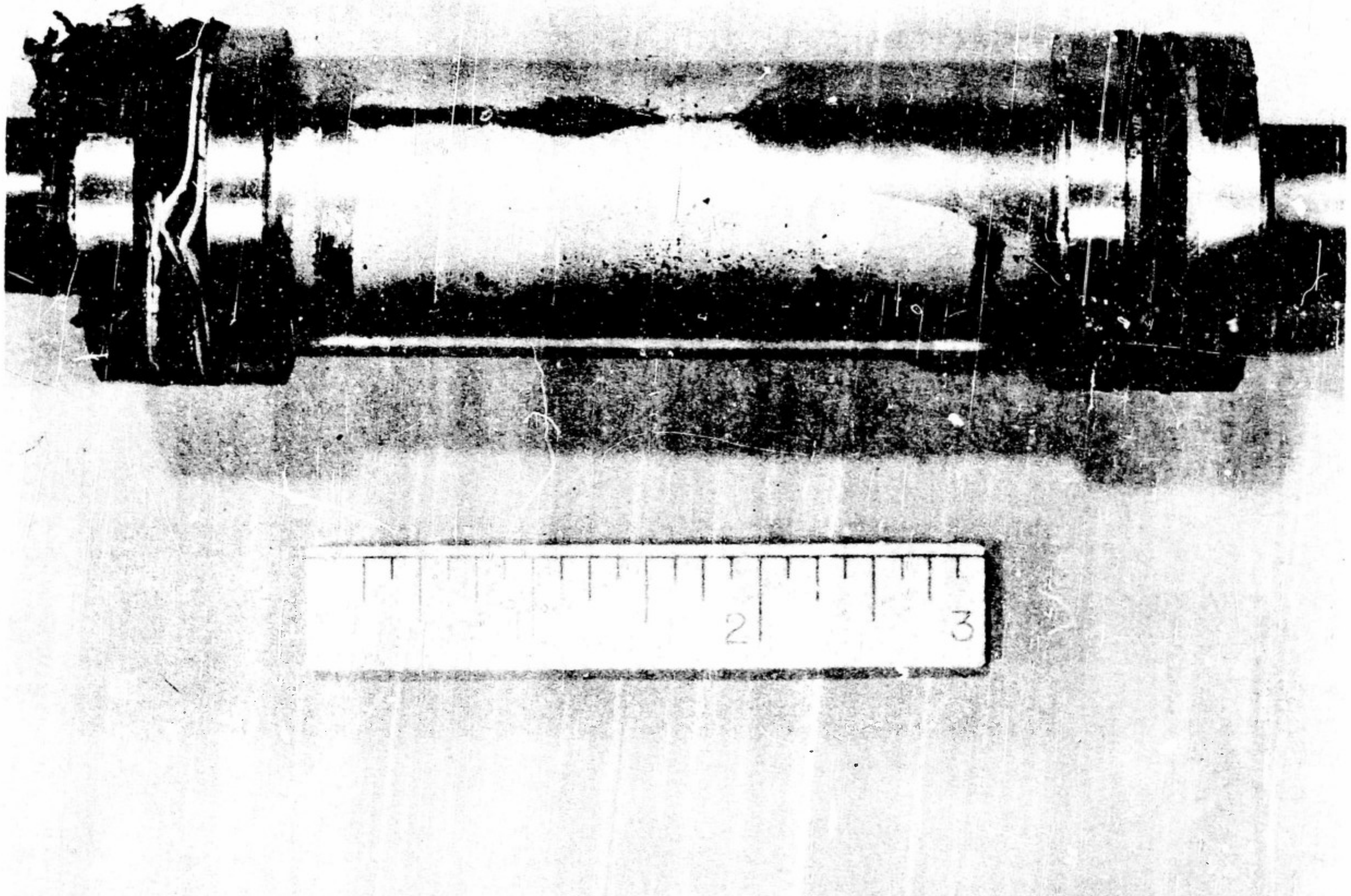

Figure V - Comparison Test - Neoprene "W" O-ring with split spiral bronze back-up and Hycar PA-21 O-ring with Teflon back-up. OS-45-1 fluid at 450°F and 3000 psi between the seals. Hycar failed at 33,000 cycles. No leakage occurred past the Neoprene seals.

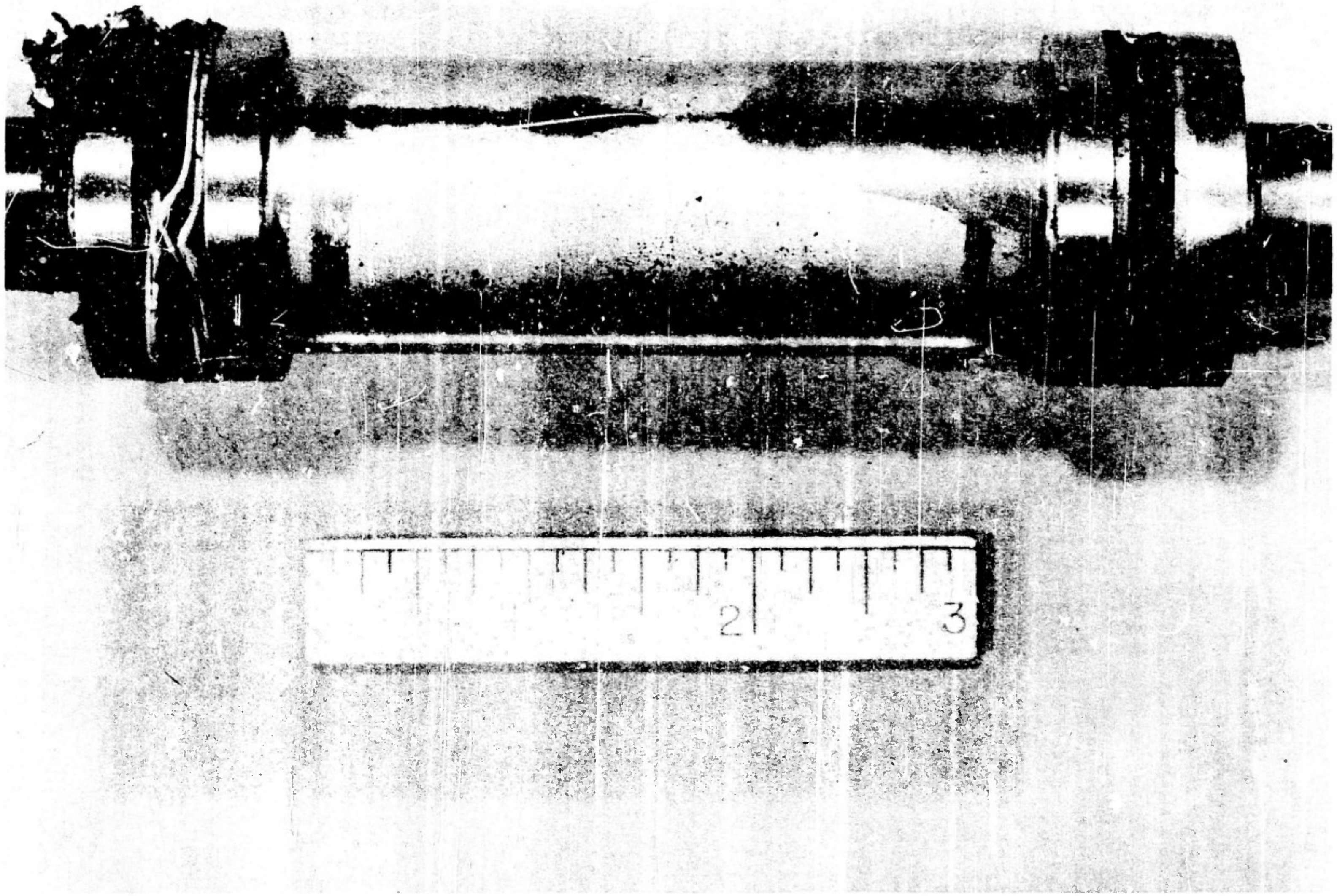

Figure V - Comparison Test - Neoprene "W" O-ring with split spiral bronze back-up and Hycar PA-21 O-ring with Teflon back-up. OS-45-1 fluid at 450°F and 3000 psi between the seals. Hycar failed at 33,000 cycles. No leakage occurred past the Neoprene seals.

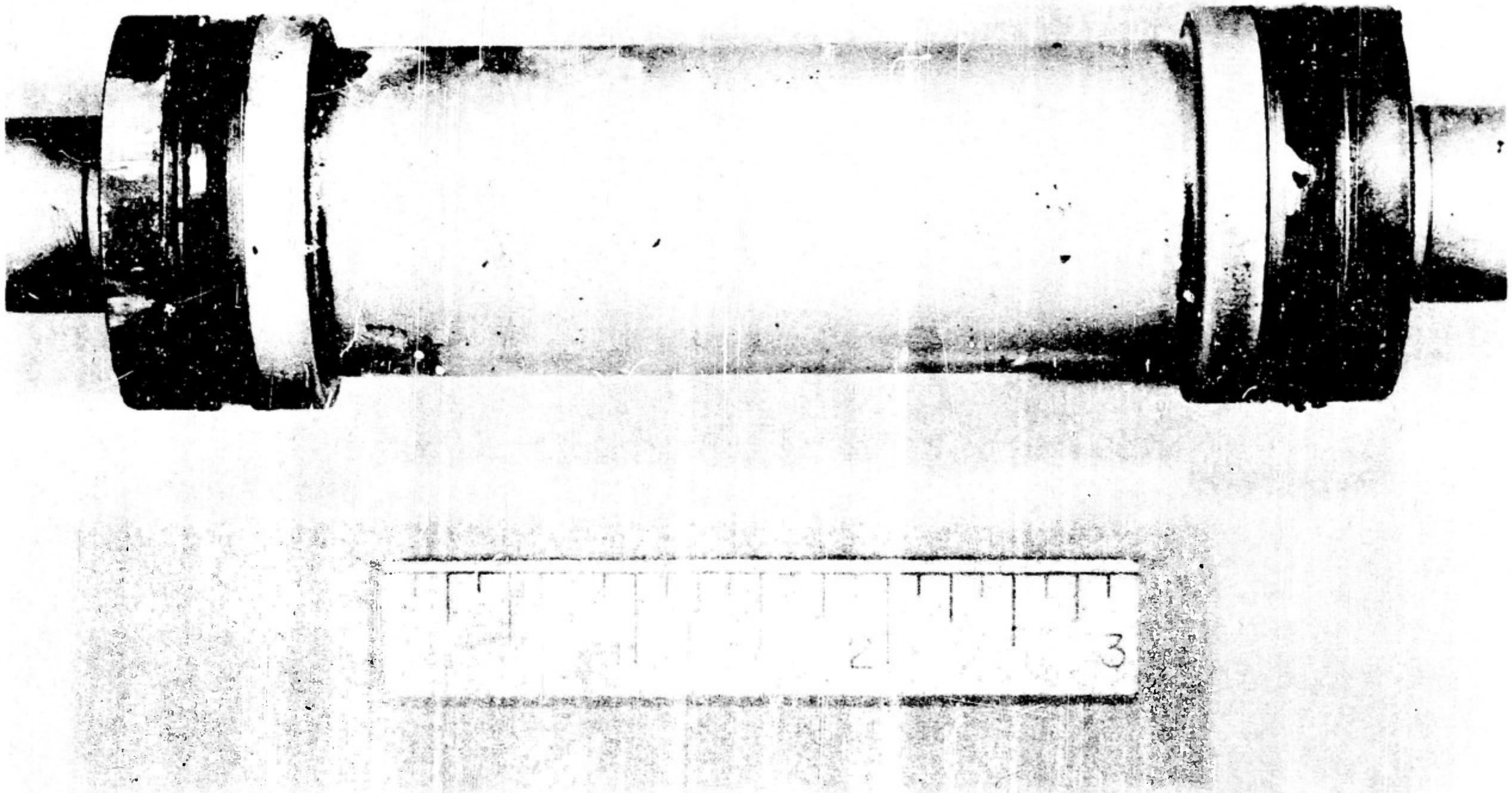

Figure VI - Neoprene "W" O-rings with split spiral bronze back-up rings. These seals operated without any leakage for 19,607 cycles at 500°F at which point failure by break-up of the O-ring occurred.

PART II B

Group Discussion

MR. CHATTLER: Good morning, gentlemen. I trust you all had a pleasant evening in Washington last night.

The first thing we'll cover this morning is fluids, packings and materials. We have a spec--or a proposed spec--on high temperature hydraulic fluid, which we will pass out at this time.

Will you please take out your copy of the 18 December WADC-BUAER meeting? It should be dated in the corner the 18th.

I suppose you've gathered--if you've read over the minutes of the three meetings we've had--that we're trying to formulate some program to help reach the objective of getting a high temperature hydraulic system and one that would be in some sort of a standard form.

You'll notice that we had selected two temperature ranges. The first temperature range we selected was 275 degrees F, based on using MIL-O-5606 fluids.

During our meetings with the material people at Wright Field, and based on the information that they received from Penn State, we felt that the 275 degrees temperature was a temperature that had sufficient margin so that we would not have a problem in using the fluid.

The thermal stability of the fluid was still very good at that temperature providing you did not have too much oxidation. On the basis of system design, we felt it probably would be necessary to specify an airless type system for 5606 above 200 degrees F, so I'd like to open the discussion on temperature limit for MIL-O-5606.

Do you have any questions? We have Dr. Klaus from Penn State here. Yesterday he gave you a copy of the Penn State report. (See Appendix 3) We also have open for discussion a proposal to select the temperature limit of 275 degrees F. With this temperature we hope to be able to use several of the standard packings on the QPL list. Does anyone have any questions on that temperature or the 5606 fluid being used at that temperature?

MR. WILLIAMS, CONVAIR: Will you define the 275 degrees, is that comparable to our 160 or is it a hot spot or bulk oil temperature?

MR. CHATTLER: This is the maximum temperature any place in the system.

MR. WILLIAMS: This would be in effect then a hot spot.

MR. CHATTLER: Yes. If you wanted to go above that we should go into the second range of fluids.

MR.WILLIAMS: Leo, by "Hot spot" don't you think it's in the tubing or in that nature would it run beyond the 275?

MR. CHATTLER: We've thought about that. You still have that fluid. If you start breaking that down, even though it's in a column, you would be continually breaking down new colums every time you actuated the system.

MEMBER: That could be covered by changing fluid in the system.

MR. CHATTLER: I don't think it would be justified to change the fluid in the system every so many hours; however, we could consider changing the reservoir fluid. On the other hand most of your new airplanes don't have anything but a 30 or 60 cubic inch compensator.

LT. KING: Leo, there is no permanent breakdown of fluid.

MR. CHATTLER: What if we have a system going to high temperature at some particular spot, what happens to the fluid?

LT.KING: I'm quoting data compiled now by Penn State people under contract to us, and 5606, under all lab tests appears to be thermally stable up to 500. Let's qualify this.

Laboratory tests--there's no flight data on it, of course.

Thermally stable--that is not oxidative stability.

In other words, in a completely closed system your thermal stability would be adequate to 500. You've got a factor in 5606--I'm parading for Dr. Klaus; maybe he'd like to take over on it.

DR. KLAUS: In this case, where you had a closed system, you could put up with that much vapor pressure where you wouldn't volatilize the lower components. Our tests indicate the material is satisfactory to 500.

MR. CHATTLER: How about the pump wear?

DR. KLAUS: You're talking about hot spots? In terms of tests of thermal stability or oxidation stability, there's no reason why the fluid shouldn't be satisfactory in hot spots above this 275; that is, in a tube where it is fairly well confined.

You wouldn't want to go spraying it around in the air at that temperature, but in a hot spot in a tube, it should be staisfactory well above 275.

MR. CHATTLER: It doesn't break down?

DR. KLAUS: No.

MR. CHATTLER: It mixes in with the rest of the system and would be all right.

DR. KLAUS: Right. However, I think 275 is a fairly realistic limit for the bulk oil temperature.

MR. LUDWIG: I have some actual service data on that point. We tried to reconfigure some orifice valves by pouring type metal in them. This material promptly melted out when we ran the valves. It came out in round BB shots. This temperature was in the order of 400 degrees yet the oil's okay.

MR. CHATTLER: Then can someone make a recommendation on how high we want to go in hot spots?

MEMBER: Shouldn't we consider the effect of the "O" ring at that temperature? I'm thinking in terms of tubing itself. That's a separate proposition.

MR. CHATTLER: That would be limited to the packing.

MEMBER: Would the bulk temperature of 275 be acceptable for our packing?

MR. CHATTLER: We'll get to that in a moment. For the moment, a hot spot, a closed section of tubing, or even a cylinder with special packings in it someplace, how high can we go with 5606?

DR. KLAUS: How high do you want to go?

MR. CHATTLER: A thousand degrees.

DR. KLAUS: That's a little high. We have run oxidation tests at 500 degrees with this type of material and find that as long as the amount of oxygen is limited to the amount of oxygen you might expect in the hydraulic system--I think there's some data here as to how many cubic feet of air we mix with hydraulic fluid--as long as you keep the amount of air low, the properties in the fluid are pretty good. You don't start to form slugs unless . . .

MR. CHATTLER: Does anybody want to nominate a temperature?

DR. KLAUS: The limitations are going to be something other than the fluid properties themselves.

DR. MORETON: I think we have to be reasonable about that. I admit Dr. Klaus has data on that, but you'll run into trouble with your industrial safety people. You'll run into trouble in operations, and when you start climbing above a hundred degrees you'll have high vapor trouble.

You're heading for the barn when you're talking about that. That's why they have these flashpoint things. They aren't safety precautions from a fire standpoint as far as initial evaporation goes. It's going to be all right as long as it's confined, but you're taking a lot of changes, I think, with electrical equipment if you can't absolutely guarantee that confinement.

If you spat 366 fluid at 350 degrees in the vicinity of any open electrical equipment you're nicely cocked and primed for a big explosion.

I, for one, would place very small odds on that occurring, but you try and tell a lot of safety people.

MR. CHATTLER: Do you say 100 degrees above the flashpoint?

DR. MORETON: I heard a lot of discussion yesterday from Lt. King of the disadvantages of having a flashpoint above an operating temperature. Then, the first thing I know, 24 hours later, they're trying to jazz up the petroleum to make it more inflammable; one of the two is wrong.

LT. KING: I think Dr. Moreton has a good point there. I think you made the statement that this is laboratory data. You asked us what the thermal stability of the thing is and we quoted it. You people have to put this fluid in the system. I think Dr. Moreton has a good point there; if a hot spot leaked in an airplane.

MR. CHATTLER: We're talking about the flashpoint. Was that flashpoint that you were talking about on the 8200 fluid also?

LT. KING: In the 8200, we ran no vapor phase phenomena and have no data on 5606.

DR. MORETON: You mentioned flash also, didn't you?

LT. KING: Yes; the reason for that reduced flashpoint, which is a fair measure and measure volatility or vapor pressure, I think in the original WADC-BUAER meetings where this 275 was discussed from the standpoint of packings, the system people would recommend you consider that as an overall high temperature operating limit.

From the standpoint of the fluid itself, calling the shots, is it stable? Yes, it is stable, but as a system designer you have other things to consider.

MR. CHATTLER: When talking about a small section--if you had a break, you'd pour out a small section of hot fluid. Then, of course, that would start your fire.

LT. KING: Do you cool that small section?

MR. IRWIN: You're missing a point. I'm speaking of a closed area in a hot spot. We recognize the fire hazard in any case where the temperature is 200 or 4 or 500 degrees. You have the same problem of fuel. If you have a leak you're going to have a fire. Let's talk about normal operations. We're going to have a fire if we're going to dump MIL-5606 on something hot.

MR. POLLARD: There's another thing we have to consider in connection with the hot spots and that is whether the fluid will be stagnant or circulating. It can stand more if it's circulating through the lines almost constantly than where it's stagnant and you get the full effect of the heat.

MR. CHATTLER: For the purposes of the flashpoint and the danger of a break in any area, of course the columns circulated or standing still, if it came up to that temperature you'd have the hazard.

I'd like to follow up a little more on the 8200 fluid. Lt. King, you said you had a problem of a flash when this fluid hits the atmosphere.

LT. KING: In some of George Keller's testing he noted that we ran into a phenomena that we can call a vapor phase operation. As he slowly heated the fluid the temperature of the vapor above the fluid was greater than the temperature of the fluid. That increment increased to a point of burning.

Therefore, we had the choice of doing two things. Trying to add an inhibitor which would suppress this or seeing if we can keep the amount of material in the vapor phase to a minimum. That is, maybe we can reach a minimum to where this fire point will be raised.

Therefore, instead of going in and saying we'll take a vapor pressure of 1.5 mm we went back to the old method of flashpoint. We wanted to see what happens if we put a flash of 405 on it. All indications were that it does not suffer from the oxidation.

MR. CHATTLER: Thank you. Now, how about 5606?

DR. KLAUS: I would like to make a comment on this flashpoint. Flashpoint means the fluid will burn if somebody lights it with a match. It also means, in a hydrocarbon, where it has a pressure of 10 mm, the point where it burns on a hot surface is closely related with ignitious temperature of 480 to 490.

MR. CHATTLER: If you had a break in the line exposing the fluid to atmosphere, unless you have a spark source it will not ignite?

DR. MORETON: At 366, a spark of unknown energy, isn't it or is it a hazard?

DR. KLAUS: I don't have the slightest idea.

DR. MORETON: I'd give them the answer, I do not know, but I would prefer to get the figures as low as possible.

MR. CHATTLER: How about a temperature?

CDR. WEATHERUP: At the risk of boring people, I think we have to consider this maintenance problem to make it work. Apparently the oil is satisfactory as far as its physical properties, but when you get to the clerical problem of stating that we'll permit a hot spot of this temperature, aren't we getting to the problem of going to the next packing?

It seems to me we're tied up with what our current packing will stand. It would be foolish, it seems to me, to permit a hot spot of higher temperature than we can expect in our current packing.

MR. KIBELE: It's related to duration of the temperature, and we've had a hot spot in the red oil system in brakes. I've seen them with disc type brakes where they were cherry red, but the duration was short and it doesn't burn up the packings in the brakes.

MEMBER: It wasn't up to 160 degrees, I'm sure.

MR. KIBELE: I didn't mean to indicate that.

MR. MURPHY: On DC-7 brakes, and they're getting pretty hot, and it was running 180 degrees.

MEMBER: We corrected it and took it to 200.

DR. MORETON: I have seen some data on rejected takeoff tests where they measured maximum fluid cavity tests after maximum soak on rejected takeoff where molten steel was running off these cherry red or white hot discs you mentioned, but apparently the heat pattern itself was fortuitous enough that it doesn't get into the oil. By the same token, that wouldn't be the same in laboratory tests, notwithstanding the fact that I think you would be running down. The acid number is up and the variable minimum is up.

MR. MURPHY: The backplates under that same condition were running 340 degrees.

MR. MIDDLETON: Our test results indicate something very similar. On our rejected takeoff tests we've measured fluid temperatures around 180 degrees, with the brake temperatures running 350 or pretty close to that.

MR. CHATTLER: We have measured temperatures up around 250 on some of the brakes on some of the airplanes.

MR. MIDDLETON: In the fluid?

MR. CHATTLER: Yes.

MR. MURPHY: At this Western ARTC Meeting they had not too long ago, they set 250 as the top limit; and McDonnell had 250 as their requirements.

MR. IRWIN: That's right. Bulk oil, 250, 275; allowing hot spots in the system, something above that.

MR. MIDDLETON: How much of a hot spot is it going to be, a foot long or so many square feet?

MR. CHATTLER: We'll set it up for the moment as 275 degree limit, depending on hot spots of the area.

MR. IRWIN: Any hot spots to be approved by the services.

MR. FIELDS: It may not be strictly along the line here, but I'd like to talk about a little ancient history in this game.

We've had 5606 under some of its former names for a good many years. In those days I was with a different company. But they all had the same experience. They were unloader systems in general in use and we designed to 160 and we thought that's what we had.

We found in practice everybody carried a little mallet because their unloader valve stuck and when it got hot you could smell it all over the place, if somebody touched it you'd get steam like a housewife's iron, then they'd pound it with the mallet until it got loose again. That's proof we're certainly way above what we had anticipated.

I don't think we want to get to the absolute limit on these things. We're not going to have the same trouble, but somebody always thinks up some trouble to anticipate.

MR. GREEN: I think, after hearing all the discussion, that you summed it up pretty well. Leo, that 275 looks like a practical value. We may be able to go higher in hot spots where there are no packings and just plain tubing. We may have to keep it lower than that in other places, but generally speaking, 275 sounds like a workable value.

MR. FERENS: I go along with the safety side of this and suggest further that--and recognize too--that we probably should put some limit on the compartment and structure temperature where these fluids are. Even though you're down to a 275 fluid, if you take a 350 spot, you're worse off.

MR. CHATTLER: That's what the hot spot is.

MR. FERENS: It's not the fluid or packings, but the safety of this particular fluid you're playing with. I suggest we add that right in the limit, that you shouldn't go over say 275 or 300 on the structure temperature or any of the components in the compartment, electrical, solenoid, et cetera. You'll eventually put it on when accidents occur, and you might as well recognize it.

MR. MAGEE, WADC: I apparently am one that doesn't know anything about oils. I'm a metallurgist at Wright Field. From our point of view, we're interested in the safety of the aircraft.

I've seen thousands of burned aircraft due to leakage that has occurred due to fatigue fractures. I know all of you must have seen some of this tubing after maintenance has gotten a hold of it, full of nicks and everything else.

You're liable to have a fatigue fracture any place, hot spot or no hot spot in a structure above or below temperature. If you can possibly avoid something that may cause a fire, I think you should consider that right here.

That comes into my field. As I say, I know nothing about your flashpoint of oils, but I do know something about materials.

MR. CHATTLER: I'm sort of influenced on stretching the point a little bit.

MR. MURPHY: You're stretched right now at 275.

MR. CHATTLER: My main purpose on that is when someone can demonstrate, performance-wise, that we fall down at 275, and can increase performance-wise by another fluid, then I'd like to consider a change, because the problem of performance is number 1 on our list.

I feel that the fluid that will give us the flight performance is the one we should use, and all other matters should be secondary.

DR. MORETON: Like safety?

MR. CHATTLER: All the safety measures in the world won't help you if you can't put the airplane in the air.

DR. MORETON: Yesterday you said you want to know where the hot spots are.

MR. CHATTLER: For reliability, I did not say safety. For reasons of performance and reliability we want to know what the hot spot temperatures are.

Still I think it's been our good or unfortunate experience to have witnessed what can happen to performance if the hydraulic system does not work. Therefore, in the type systems we're getting now, performance has to be number 1 you're not going to take off the ground unless they work.

MR. KIBELE: Aren't we speaking here of specific temperature and don't you have to tie in a requirement that we have compatability to any temperature we design to, and all the factors we brought up? All of us have to take into account what packings we use.

MR. CHATTLER: I probably didn't state, Bob, that we selected the temperature on the basis of packings and the pump tests that have been run. That's why even though Lt. King says 550 degrees F on the MIL-O-5606 fluid, we kept chopping it and going back down the line to where we felt we can get along almost with the system we have today and still go to 275 degrees.

MR. KIBELE: We're talking about some value of hot spot. In one man's opinion, he's thinking of a hub; someone else may think of an actuator. We have to have compatability regardless. With the normal exceptions that come in on certain hot spot areas of 275. Shell Research has an article that goes into spontaneous temperature and shows that when pressure in the hydraulic system goes down, the temperature goes down sharply.

There were so many other factors involved that very often you can exceed the temperature yet nothing seems to happen. This is the first of a number of articles they plan on running. It's rather difficult to determine spontaneous ignition temperature at normal pressures. I just got this before I came here.

It's the Shell Aviation News, September, 1953 issue.

MR. MURPHY: I'd like to bring up a point: Howard hit on it a little bit. I can't think of a better hot spot than a relief valve. You're going to have a hot spot. It may be an emergency system, where the system got jammed. If you're talking about that condition, you have the packing problem, but you sure have a hot spot.

MR. CHATTLER: We're talking about a designed hot spot. As a matter of fact, you ran some tests for us on your DC-6, blowing off the relief valve to 380 degrees F and we accepted it as an emergency condition.

MR. MURPHY: We have another item there that takes care of it.

LT. KING: I don't want to go on record for recommending overall use of 5606 for 500 degrees. We quoted lab data, as I said before. Isn't there some data available right now?

MR. CHATTLER: Well, I don't know. Jack Ludwig said they ran tests to 250.

LT. KING: I'm thinking maybe Frank Straus or Bob Green may have obtained information that could be made available.

MR. CHATTLER: In selecting this temperature, we want to get started testing equipment at 275 degrees. If we pick this point, we can all get started. If, after a certain amount of tests that we all may be engaged in, we find this is ridiculous, there's only one way to go.

LT. KING: I'm thinking of the X-3. There, if you got da you're taking it out of the 'guesstimates' and making it an actuality.

MR. MURPHY: We certainly didn't want to run 5606 fluid at 300 degrees on the X-3. As far as I know, the high temperature program started with the X-3 because we wanted a different fluid than 5606.

MR. CHATTLER: Why didn't you use one?

MR. MURPHY: It was not available.

MR. PROMISEL: Well, in talking about hot spots, you better talk about the other materials than the fluid itself. Because most of your designs are based somewhere on the order of 160 degrees. If you are talking of 350 or 400 degrees, properties of your aluminum alloys drop down badly too. These are not only static properties, but fatigue properties. You're increasing failure from a number of other sources.

If you're going to talk hot spots, I think you should design the hot spots carefully with respect to location of materials in the hot spot areas, size of hot spots, conductivity of materials in the adjacent area, and a lot of other things.

MR. CHATTLER: Then we all agree on 275 degrees F and require that deviations be obtained for hot spot areas where the fluid temperature is above 275 degrees. Any other comments.

MR. BUMB: The only thing I could say about the temperature, I think it ought to be understood this isn't a magic temperature; that's okay, but that we have to probably, for the time being, face it--I don't think it ought to be accepted by everyone that here's a temperature that's okay.

I don't think it's healthy, but I think we're going to have to buy it. In other words, with our testing, we came up with the idea that units are possibly good at 250, on the basis of testing we have done. We won't say that 275 is 25 degrees too high. We think it's a logical, passible temperature.

But I don't think anybody should say 275 is as good as 160. Everybody should be looking for new fluid and materials as far as they can. Meanwhile, this may be tolerable. If we say we couldn't go above 160, we'd be stymied on design.

DR. KLAUS: What was the primary basis of your 250 limit for fluid and materials?

MR. BUMB: Materials such as rubber.

DR. KLAUS: I would like to say one thing. It might not be very popular. But I think if everybody is sitting back waiting for a cure-all in the fluid line, they're going to have to wait a long time.

Even the high temperature fluids that George Keller had been talking about have some of the shortcomings that red oil has. You don't necessarily increase spontaneous ignition and a lot of other things because you have a so-called high temperature fluid. You're going to have to live with some of those things.

MR. BUMB: Relative to whether we should be looking for the magic items or looking harder about how to cool a system . . .

DR. KLAUS: I like that better.

MR. CHATTLER: We have selected 275 for the moment. We all feel that this might be a usable temperature. The Air Force and the Navy are going ahead with their program of testing equipment at 275 degrees. Now, do you want to discuss that point any further?

MR. STRAUS: Along this line of picking 275, I think at the meeting we agreed on that figure because it was the limit we thought we could get out of rubber materials. At that time a lot of thought wasn't given to the fluid, but enough thought was given to it to point out that 275, looking at the oxidation characteristics, that gives us some type of usable life.

I for one--if I were designing aircraft, I would be afraid of 275, but I think it's something we can use until we get more data on it.

We're now running a 300 degrees, 5606 system, in our lab, and it's not a closed system. I notice there's a great deal of evaporation going on in the rod seals and out the reservoir, which is certainly indicative of the fact that the light ends are boiling away and it is different from the properties of the fluid. Unless this is an unknown, even if the reservoirs are filled periodically, whether the original properties of the fluids will be retained is not entirely known. I think 275 is something that's picked, and it's no indication as a positive cure-all.

MR. COLLEGEMAN: Hadn't we better call that 275 a maximum temperature rather than a usable temperature? With the understanding that every attempt will be made to keep the temperatures below 275.

MR. CHATTLER: Maximum bulk oil temperature.

MEMBER: No; bulk temperature. Anything below that.

DR. MORETON: Frank hit on a point here that had been bothering me. I believe we're talking about the use of 5606 in present systems where changes in airplane configuration due to times are forcing us to allow the temperatures to go higher; is that correct?

MR. CHATTLER: Not exactly correct; not in my way of thinking. We have to select a point where we can say that you have to use a different fluid.

DR. MORETON: You're going to let them go to a certain point. Dr. Klaus' data and Frank's data--they did look at the oxidation numbers. I can't help but agree on thermal stability. On the other hand, unfortunately, present systems and design concepts do not and cannot exclude air. Some consideration has to be given to oxidation factors. Therefore, that limit looks more appropriate.

MR. CHATTLER: As I said before, we were going to specify a closed system--an airless reservoir type of system. A system like on the F-86 or some of the airplanes we are getting from Douglas.

I felt, in that type of system we would certainly minimize the oxidation characteristics or the oxidizing of fluids. So the present system wouldn't be acceptable where you have a pressurized reservoir pouring volumes of air into the tank or letting it blow off.

DR. MORETON: Get rid of the fluid in the tank and leave, say 50 cc at the bottom.

MR. CHATTLER: These will hold, for some temperature range, 250 to 275.

MR. FIELDS: I want to know whether we're going to think about this as a continuous temperature or whether it's for a short duration. It normally runs a short time. One thing is the heat generated in the system itself. Another thing is due to aerodynamic heating on some of the modern airplanes, and the third thing is the fact that we're getting down where instead of having a nice big fuselage, we get ourselves an engine, a big blow torch, and wrap the outer skin as tight as we can around it.

So we get heating from that sort of thing. That does not change aerodynamics, but it may be rather difficult from the cooling standpoint, with some possible exceptions, but it can't be a very great duration. On most airplanes, you simply can't carry enough fuel and you can't drill enough oil wells to run them at Mach 2 for very long when the aerodynamics becomes serious. If we talk about 275, is that at the peak of these things, and normally it runs 200 degrees, or is it 275 all the time?

MR. CHATTLER: That's really the peak. In other words, this is the peak of the bulk oil temperature so it means you're not going to be at 275 all the time, but it is the so-called upper limit of the fluid and I wanted to set a demarcation line at that point so that if everybody sees they're over that limit, that they arbitrarily not say, "We'll see if we can get by on it," but go to the next step fluid.

If we start using a new high temperature fluid gradually in experimental airplanes, we'll probably progress more rapidly than if we convert other airplanes after we find we have a problem. So we're set on the 275 degrees F for MIL-O-5606 fluid.

Now, paragraph 3A2 where we spoke of cadmium plate, copper, tin and zinc as being very questionable items in a system that may be permitted to go up to 275 degrees F.

DR. KLAUS: Everything but tin and zinc are in the MIL-O-5606 High Temperature Report. (See Appendix 3)

LT. KING: Also, a recommendation made, Elmer, on magnesium; do you want to cover that?

DR. KLAUS: Magnesium is easily corroded in any system where it stands a chance of forming water on oxidation. In the lab, it's difficult to keep down magnesium corrosion in any oxidation tests in the order of 350 to 400 degrees. It becomes virtually impossible to cut down magnesium corrosion.

MR. CHATTLER: Everyone please take note of these points; we will try to give you more information in the report.

Now Item B, based on the developments, we selected as an accomplishable temperature or a realizable temperature, a fluid temperature of 400 degrees F as our second step.

There was some comment yesterday by Mr. Kleven of Convair where he felt that this temperature was 50 degrees too high. Is this acceptable to the group as our second step?

MR. FERENS: The next page mentions: "All future work will be concentrated on MLO-8200 fluid, unless more promising fluids are found, as this fluid is the most advanced in its field."

You're putting the cart before the horse here.

I was wondering whether that is the most advanced fluid in its field--based on what? Is there flight data on it or is this a laboratory thing?

MR. CHATTLER: For the moment we'll say 400 degrees is a reasonable temperature; let's get into the fluids now.

WADC AND BUAER have studied the available fluids. I was trying to obtain a fluid, some fluid so that at sometime we can say "This is our 400 degree fluid, and this is what we'll design our equipment to work with."

As I said, I want to select a fluid that we can all work with and I've always felt if you take one fluid and spend your time working on what appears to be the best fluid, that you will accomplish the end result of a good fluid-system much sooner than if a lot of people were working on lot of fluids and one fluid coming up to the fore-front that is not really THE fluid.

If that thinking isn't right, let's have other suggestions.

MEMBER: Let Doug Moreton go first.

MR. CHATTLER: The opposition at the moment, I'm sure, is between OS45 and MIL-O-8200.

DR. MORETON: That's not so.

MR. KELLER: One of the things I object to is designing a fluid, chopping it up, and a month after you get the first formulations, start writing a spec about it and saying to the industry, "That is what you should use."

MR. CHATTLER: No one has done that.

MR. KELLER: This is the third or second time--if my memory is right--we've been trying to get a hydraulic fluid. I'm interested in getting the best fluid for the operation that I can get.

We have had this OS45 and there was something you didn't like about it so we got it revised to OS45-1. I was told, "George, there's no sense in going on with OS45; this is a much better fluid."

I don't know much about chemistry--but I could take this fluid back and run it--and we found that there were a number of things about that fluid that were not at all satisfactory, and we let the sponsors of that fluid know about it to improve the fluid and make it workable.

Soon we had 6983; again they said, "George, this is the fluid. This is the fluid that's the answer to all your prayers. Use this fluid."

We took the fluid and started playing around with it and there was again something wrong with the fluid and couldn't use it.

As a matter of fact, just last Spring, as recently as that--the first version of this spec appears on Page 5. MIL F9042 was put out. I was told it wasn't written about this MLO 6982, but it happened that the requirements of the spec and the properties were identical. This is perhaps a coincidence.

We were again forced to revert to OS45-1. Now, we have MLO 8200, and we have gotten some of that fluid about 2-1/2 months ago, and we're testing it. We haven't completely evaluated it. Again, we are told this is far and beyond OS45-1.

I hate to think again of having to fight out the battle of the specs and again being forced back to OS45-1 which we find we can use.

I object strongly to the writing of specs around somebody's pet fluid. I know that Wright Field has had a contract with Cal. Research to develop fluids with them and the Cal. Research people have done an excellent job.

I think they've been hamstrung by poor requirements. But within the requirements, I think they've done an excellent job. But I think the requirements were not designed around actual operating requirements. What we need if we're going to have a spec which is an objective for a fluid is a spec which says what do we need for a fluid to put in a system and have it operate.

We do not want a spec which is written around what someone at any particular time thinks about that fluid, particularly if he's the sponsor of the fluid. I don't care whether I use OS45-1, whether it is a MIL number, an AMC number or any sort of number. What I want is the best fluid.

I suspect strongly that writing a spec around one particular fluid is not going to be the way to get us the best fluid the earliest.

The way to do it, if you must write a spec at this time, write one that says: What are we going to require of a fluid for operating at some specific temperature. This is the only way you can evaluate one fluid against another.

This sort of spec writing is automatically rejecting everything but one person's pet fluid.

MR. CHATTLER: I agree with you one-hundred percent. Can we write such a spec?

MR. KELLER: If we can't we shouldn't write the spec at this time.

MR. CHATTLER: There are people today that have to use a fluid. You people yelled bloody murder when we introduced a fluid and all the problems associated with using more than one fluid in airplanes.

If we're going to permit the individual selection of fluids and everyone may have his pet fluids, we're going to get into that situation. I'm trying to say, let's select a good fluid and work with it and make it work in our systems. Then, if a better fluid comes along, let this be a next fluid.

Has there or has there not been enough experimentation with fluids that we can do that? If there hasn't, we should set up some program of evaluating fluids. But we know as every month and year goes by each fluid is getting better and better, but people have to select fluids to use in their airplanes.

All I'm trying to determine is what should we select so some people can use a fluid and we aren't up against this terrific logistics problem which the Navy knows too well.

DR. MORETON: I have something to say too, about this whole thing.

In the first place, I'd like to get it straight in my speaking on the fluid situation, in some cases I may be talking as a member of Douglas Aircraft with Frank stomping on my instep and in other cases I'm thinking of fluid evaluation at Douglas.

I don't think it's ever been brought out in the open in front of all the effective people, Douglas Aircraft Company has for sometime been involved in a relationship with the Monsanto Chemical Company. We have nothing in mind but the developing of useful hydraulic fluids and other lubricants of a related type for purposes of selling them and making money just like you build airplanes.

The ones we make for aircraft have the least prospect and those are where we spent the most money and make the least. All of the formulations that have come up to date are Douglas Aircraft Company formulations. Monsanto, through another marketing arrangement, has done an excellent job.

I'm not here to plug my particular fluid, I just want it made clear who I'm speaking for so everybody will know that part of my talk that is a pitch and that part that is objective analysis.

I, for one, think it's high time that, as you said, you agreed if we can't write these specs with realistic tests, prescribe the requirements meeting these design engineers, let's not write them.

You have a good point, Leo, in wanting to start out on a good fluid. Nobody can argue on the desirability of having everybody agree on something, but unfortunately the facts of life are very often competitive design that takes people into different fields. It's that way with OS45.

In formulating that fluid we were specifically aware of these problems. Without one of the ingredients in it, it would definitely be better than the hydrolises test. It definitely might be better in some of its other laboratory tests, but we specifically put that ingredient in there as one example of the design concept because it made it more compatible with present packings, because we felt that a fluid that was good in the 350 to 450 range, that would get along with present packings a little better, was going to be a more valuable industry piece for the next five to ten years than one that looked nutsy up to 550. That automatically assumed you have to leave behing all the things you've been using for the last ten years.

If the choice were mine today, in view of even the numbers I heard yesterday, I'd still leave the ingredient in.

I'm convinced, after yesterday's discussions on temperature--I certainly am pleased to have heard that that fluid was cut right down the line for what they want it. Furthermore, I think there's going to be others just as good.

Maybe X corporation is going to do it. If a spec must be written, I think it ought to be written with the functional broad requirements only.

I would like to suggest that the first thing to find out is, is a spec necessary.

MR. CHATTLER: How do you buy fluids without a spec?

DR. MORETON: It's done all the time. I'd like to know the privilege of the non-spec materials that you buy every day--because they work.

Here we are at the point, searching not for standardization, but for the maximum we can get out of the aircraft. The minute you attempt early standardization you put a dead leveling floor over the competitive aspects. You give it to the designer and say, "Do the best you can with this."

MR. CHATTLER: How many sources of supply do we have for 5606?

DR. MORETON: I would imagine half a dozen.

MEMBER: Four.

MR. CHATTLER: This is, of course, the desirable situation.

DR. MORETON: Yes.

MR. CHATTLER: How did we reach the stage that we reached with 5606?

DR. MORETON: Time alone. By the time 5606 came out--it was a long time before anybody touched Standard Oil of New Jersey products. It was the sole source for a long time.

I'm sure Dr. Klaus will underwrite that statement. They finally did it, and it's an excellent fluid. I simply say that time and competition can take care of them and I don't think we can worry them down.

MR. CHATTLER: Would it have been taken care of, 5606, if a spec had not been prepared at the time?

DR. MORETON: I don't think that's necessarily so. I think competition would come up with a proper spec or no spec.

Are you procuring enough high temperature hydraulic systems equipped with hydraulic fluids so that there is a crying need for the spec?

MR. CHATTLER: How much testing was done on OS45, any other testing besides North American and Douglas?

DR. MORETON: How much experience is there on OS45 testing versus MLO 8200?

MR. CHATTLER: I just wanted to point out that it was tested in just a few places.

DR. MORETON: Far more than any fluid here, I will warrant.

MR. CHATTLER: That doesn't necessarily say that OS45 is the best fluid we have today.

DR. MORETON: No; I don't think it is. But I'm confident that there are other usable fluids.

MR. CHATTLER: Let's get to your previous point. How many people are going to need a 400 degree fluid within the next year for airplane production? You know what airplanes you're building. Do you need a 400 degree fluid?

MR. MURPHY: Do you mean are we going to need it or need it for production?

MR. CHATTLER: Can you select a fluid and say, "This is the fluid we're going to use."

MEMBER: Why not ask who is now looking for a fluid that will work at 400?

MR. CHATTLER: What I was trying to determine is how much time do we have to play around with fluids.

MR. MURPHY: Who is testing high temperature fluids?

MR. CHATTLER: We got that in yesterday's discussion. They're not testing fluids, they're testing packings.

DR. MORETON: I think there's a lot of mysticism here about the need to have a single fluid that you can develop a pump on. I would like to have Dr. Klaus' opinion on this; looking at the lubricity problem we realize what a complicated problem it is.

My impression of it is in the pump tests we've run there was a variety of synthetics over the past six years, that if you achieve a pump, for example, that is anything like the pumps we see today being tested in the high temperature programs, that if it works successfully in OS45, and somebody is testing that fluid, or it works successfully on MLO 8200, or on the Texas fluid, although there is viscosity there, that has me bothered.

But if you can get success on those, I think there's a higher degree of chance it will be satisfactory than these other types. We've tested more synthetic fluids in pumps of a variety than any other organization, I believe.

I think PRL has done more work on the chemical types but when it comes to running elevated measure piston pumps, I'm sure we've blown more money out the window than the rest.

In other words, if you get a reasonable lubricity material, and a pump goes along at 300 degrees or better and you come along with a fluid of a related type, as is the Cal. Research, for example, there's a high degree of possibility that you will run into problems.

Those problems are not necessarily affecting the technical design fixtures. If you happen to fix on OS45 and a better fluid comes along, of a related type, it doesn't mean you'll have to go back and undo the whole thing.

MR. CHATTLER: As long as we stick to the silicate base fluid.

DR. MORETON: That isn't a silicate fluid at all.

MR. CHATTLER: Is it not.

DR. MORETON: I would like to stand on the record that it is not the same structure but closely related. They have similar chemical properties. If they are the same thing, what's so year's ahead about it?

LT. KING: Leo, I heard both Dr. Moreton and Mr. Keller about these chemical tests. However, if I send a fluid, if the Texas Company sends a fluid, or if PRL sends a fluid at my request, what happens to that fluid? Does it go into a pump?

The first thing that happens, it goes into a chemical lab in the aircraft company. Why don't they then stick it in the pump and pump it? Why don't they put it in a valve? You have a means of quality control and a means of selection.

What sort of tests do they use? I don't know; these people can tell us. I do believe I saw a test report where they ran an oxidation corrosion test, on 6893, the little monster which corroded with magnesium. That may be an interesting point too.

Silicates have been known for a long time. They're quite simple to make, relatively, and when production gets up, the people up in planning and in the chemical company may say it is relatively cheap. Why haven't they been used more?

The greatest silicate production right now is used for one purpose. It's used in treating buildings. They use silicate hydrolysis on the building for a coating purpose. Therefore, in that case they use the hydrolytic instability of ethel-silicate for that purpose.

If you're looking for physical properties influencing it, take your straight chain silicates. They'll give you the physical properties. Why don't we use them?

I think if you're looking also for thermo stability, you can take a fenil narial silicate and use them as heat transfer media and it is better than daltherm, but unstable. You get water in them.

If you can't take a resinous material in the system, I don't think you can take a silicate in the system. Until you decided to design an aircraft hydraulic system to exclude in any way shape or form water, or the presence of moisture, even in small quantities, then I think the materials in the general class, of which are known to be hydrolytically unstable, we need a hydrolyitic stability test.

MR. KELLER: One thing I don't do, as a matter of fact, is believe anybody else on anything like heat. I have gotten myself into trouble that way before.

We have certain things which we believe are necessary for us to know in order to tell whether something is going to operate satisfactorily in a hydraulic system. One is operating the hydraulic system. We have other chemical lab tests which we think are mighty important. Some of them we make regularly, and I don't see it in the spec.

MR. CHATTLER: This is a proposed spec, George.

MR. KELLER: I have suggested that they include these items. We make some of these tests, and on the basis of some of these tests which do not appear, at least one of the previous MLO fluids would be completely undesirable for a hydraulic system of which I had any part.

So we still find it necessary to check the data that the producers of the fluid give us. We find it necessary to conduct such additional tests that we, as builders of hydraulic systems and not as manufacturers, feel are important in the actual operation of the hydraulic system.

MR. CHATTLER: Are you talking in 400 degrees?

MR. KELLER: Yes. We don't have a pump that will go to 550, so we are forced to talk in the 400 degree range.

We have been operating a silicate ester fluid in this case--it happens to be OS45-1, merely because we have not been successful, in the course of a long, costly, extensive search, for other fluids, we have not been able to find any fluid as good. I hope MLO 8200 will be as good or better.

Until we find others, we're going to stick with that fluid which we think is the best. We have been operating test stands in our lab for pretty nearly a year at very high, very low and normal operating terms in an exposed location out in our back yard, a place where the wind will whip in, and when we get rain in California, that comes in there too, and we have not had any difficulty in operation or storage of the normal fluid in those areas, and we have not taken any particular precautions in storing them, over and above that which we will take in any fluid--we don't sit it out in the rainstorm. We won't do it with red oil, MLO 8200 or OS45. We have close contact with our field work. On the basis of actual operating experience under conditions not entirely optimum at all times, I don't believe we have a hydrolysis problem.

MR. CHATTLER: Where are the machines located?

MR. KELLER: Out in our back yard. The OS45 is not being handled any different than the red oil we have.

MR. CHATTLER: I don't think you can make the statement that hydrolysis cannot be a problem. We know we get water in our system.

MR. KELLER: Four-hundred degrees. I wonder if any test was performed to test it with steam. That perhaps should be the test we make.

MR. CHATTLER: We're not going to start arguing about individual tests.

LT. KING: Leo, I'm just an old lab hacker; maybe Dr. Klaus could bear me out on this. If we take a material that reacts with another material, such as the

possibility of a silicate reacting with water, that sets a room temperature, and you heat it up to 400 degrees, you just don't distill the water out. You have a reaction taking place.

I was a lousy student in physical chemistry, but as I recall the case, that reaction is doubled for every 10 degrees rise C in temperature. So although you may drive most of the water out, you may still have hydrolysis.

DR. MORETON: I did not mean to imply that a hydrolytic stability test was . . . you choose the word, incidental. I do say, if we do decide--because we're going to hydraulic instability history--to use these things, do not impose it on a fluid or use it to exclude a fluid until you know that it correlates, or have reason to believe that the correlation with the service condition that it attempts to duplicate.

I can assure you, we are just as acquainted as the military labs in the services as to the stability of these things. We're just as concerned with the integrity of the product. All I can do is again assure you, if we thought it was a major problem, we'd do something about it.

We recognize it isn't as stable as the one you propose. We consider it is more than safe for the type of systems these gentlemen have to consider. We've been fortunate to live next door to the people that do that type of thinking for a great many years.

MR. CHATTLER: Whatever fluid we come up with, Dr. Moreton, regardless of all the tests George Keller runs, or other people run, about two years after you have it out in the airplane, then you'll know what your problems are.

LT. KING: When I mention tests, I'm not referring to materials, any specific fluid, magic X or P or anything, but I was referring to this (indicating).

If we, in our little glass cases, have missed the boat on a hydraulic fluid, this proposed spec is a plea to you people that use it to help us out. This is not the same little monster that went out the first time.

MR. CHATTLER: I was going to call for that.

LT. KING: Just a minute. So far as viscosity, we have shown, and Penn State College has shown, that you can pump with an efficiency of somewhere above 85 percent in the small pump they use, to a viscosity of less than 1.4 centistokes. You people have to use them.

The original requirements have been 3 centistokes at the maximum temperature designed to use. You'll give the fluid people a break by cutting it down, but will it cause trouble? You're going to have to decide that by tests.

Total credit for this is to Penn State College. Lubricity was adequate to 1.85 in the one we're discussing. I think it would be fairly safe to say right now, providing material is silicate you will have a fair margin of lubricity at 1.5 or 1.4 centistokes. But this is from a chemical aspect, a hydraulic fluid aspect. It is only proposed. In the case of your pump test, if you have a better wear test, let's put it in. But running 4-ball wear test does not always work. The pump's the only thing.

Hydrolytic stability; as long as you work in an aircraft plant, you don't have that problem as you do out in the field. When you have airplanes that heat up 350 to 400 degrees, you come back down.

I heard you couldn't exclude air from the hydraulic system. We live in a water atmosphere. If you want the system to eliminate hydrolysis, let's throw the test out, so you don't have to run it.

The second point is, we at the Field and you in the Navy have been the same. We're locking at anything and everything. We were given a mess of requirements to develop a hydraulic fluid. We got the materials somewhat to meet those requirements.

Now industry, with their technology, will definitely produce a better fluid as time goes on. The only way we'll tell is to test everything and anything that goes

on. We're open to test anything and everything that goes on.

MR. CHATTLER: The Navy and Air Force will test fluids for a period of a year, let's say, maybe one more year will give us the time we need to be able to select a fluid at some particular stopping point and I feel that we're going to have to do this because, otherwise we're going to be in a position to have to approve a variety of fluids in production airplanes.

The purpose of this meeting was to coordinate this program; thus, all comments were in order. We'll test MLO 8200 and 0845 in system and component tests.

If anybody knows of any other fluids, let us know, We'll concentrate on the ones we know most about. Let's say a year from today we'll have a lot more test information. Then we'll try to select a fluid for the -65 degrees F to +400 degrees F range.

In the interim, I'd like all comments on the proposed spec. Please send your comments to WADC and BUAER.

I'd like to get comments also on the hydrolytic stability requirement in a 400 degree fluid. Do you want to explain hydrolytic stability, please, Dr. Klaus?

DR. KLAUS: I'd rather not be quoted. Hydrolytic stability is fairly simple. You mix water with a fluid under any condition and does the fluid fall apart, and as an idea, do you have sludge? That's what it means.

I want to establish that Penn State doesn't sell a darn thing. While we're speaking of fluids with experience, I think perhaps if we're talking about a 400 degree hydraulic fluid, some consideration should be given to the fluid that has the most practical experience than any of these ester fluids, such as MIL 8708, which is fairly close to your specs.

In some cases, things like the alternator drive have been run with a jet on it. Esters can be made to 2500 centistokes minus 65 limit. They have been tested at high temperature. I would like to see the argument get off, "Is my silicate better than your silicate?" and perhaps look at some other fluids.

MR. CHATTLER: If anyone knows of a fluid they think we should be working on, write WADC or BUAER.

DR. MORETON: As you know, I'm against this spec being used even for exhibit purposes and I would like to make a suggestion that this year plan that you propose sounds to us like a very reasonable approach.

I would like to further suggest that at the end of that year you give consideration to--instead of having any single person supporting his or her fluid or ideas, that the job be turned over to the Hydraulics Committee of the SAE, who is familiar with this work.

This is the way we resolved the non-inflammable question. Everybody agreed, including the servies, as the result of that a workable joint plan came out of it. I don't see how we can bypass the opportunity to follow the same road.

I'm assured that Bob Terry, or whoever is Chairman, would appoint a group of individuals to represent both sides of the problem.

MR. CHATTLER: Who wrote that non-inflammable spec? I never saw it.

DR. MORETON: The Navy did.

MR. CHATTLER: Have the hydraulics engineers do it.

DR. MORETON: Let the men who have the requirements decide what the requirement is and if they need chemical help from me, Monsanto, Dr. Klaus or the Services, they should all be held at the same degree of knowledge.

I'm merely suggesting that if industry must live with a spec on hydraulic fluids and design airplanes for those specs, you people should be able to guide the thing and determine when we are going too far and not some service's laboratory. I

think this is the wrong approach.

MR. CHATTLER: Here's a spec. This can be made into a spec that would be agreeable to a lot of people. A spec may originate from anyone, but then this spec is thrown at the mercy of the group. Each one has an opportunity to comment on it. They make a survey, and the majority rules in the paragraphs that go into the spec. I don't see why we can't do that.

DR. MORETON: Use it for a teeing off? We've bypassed those things long enough.

MR. CHATTLER: This will be a coordinated spec by everybody in this room.

MR. BARTHOLOMEW: I'd like to interject one slight word of caution. I've yet to have an aircraft manufacturer come up to me--if one of you come in and says, "I have a chlorinated Panther here and it's going to take your rubber suppliers to come up with an adequate rubber, if that can be done." The sooner a fluid is established the quicker you will get elasticity.

George Keller presented data yesterday on 400 degrees F. That work was done on a compound developed two years ago, and probably not anywhere near hydraulic system use. Dr. Klaus mentioned the use of diesters. According to what I hear from the engine people, they're limiting the use in engines. They have to cool their engines, just because there's no hose or seals in contact with diesters.

Consider the fact that the quicker you standardize on the fluid, we in the rubber industry will get you rubber seals.

MR. CHATTLER: Dr. Moreton, with one single sole exception, there has never been a spec that's come out on hydraulics that hasn't been well coordinated with all the people concerned.

Of course, you realize, in any spec somebody has to make a decision because there's a great deal of differences of opinion. But I think we have done real well in the A6 Committee on our specs.

If we could get these people to spend enough time to think and to read this fluid spec and understand what those individual requirements are and what they mean. For example, this problem of close tolerance valves, silting, this probably should be a requirement of the spec.

DR. MORETON: It should be. That's the sort of thing we really need.

MR. FIELDS: It looks like you're up to where I like to see it. I'm not a chemist. If it's a chemical term I know nothing about it. The only point I have to make, the darn things work sooner or later.

Can we write a spec actually that comes down to the mechanical engineer level rather than to the chemists level? I don't know whether it can be done. It would certainly help if we could put our requirements in our own language.

MR. CHATTLER: We'll keep that in mind.

<u>The next subject is packings.</u> This is Item IV(A) on page 3 of the 18 December minutes. It stated there that WADC was preparing a packing spec for 275 degrees F.

Since this specification will parallel the present spec very closely except for temperature limits and possibly aging, I expect the specification to be issued at an early date and I would like to get started on qualifying packings as soon as possible for 275 degrees F limit.

Based on the WADC contracted Santa Monica, Douglas cycling tests we have found the PRP, Los Angeles, and PRP Dayton, AN6227 standard compounds may be able to pass the 275 degrees F proposed spec, so we are going to undertake to try and qualify these packings first.

Of course, as the spec becomes finalized, anyone of the packing manufacturers is in a position to submit his new packings compounds for qualification.

At the next A-6 meeting, we'll try to have the spec available for the people so that they can all get started in submitting compounds for the 275 degrees F group. We'll not dissolve the present 160 degrees F group. We want to come out with another QPL that will give us a 275 degrees F range.

Any comments on that program?

MR. FERENS: As I understand, you're going to take the packings that you have here, find out which is the best, and draw a spec around that?

MR. CHATTLER: No, to the best of our knowledge, we're going to prepare a spec for 275 degrees F, then take the compounds and see if they pass that spec.

MR. FERENS: In other words, a performance spec?

MR. CHATTLER: That's correct.

MR. MURPHY: But you'll change the numbers in there?

MR. CHATTLER: Correct.

MR. STRAUS: That was an easy spec to write, because we just took the 5516 and changed some temperatures, and erased the allowable swell.

There is one question I'd like to throw on the table, and that is one of correcting leakage. There's a possibility there will be no leakage. In other words, it will either evaporate away or burn away. I think there should be some method manufacturers can use whereby there will be consistency in measuring leakage at 275 degrees F.

Douglas has done a lot of work, and they would be in a position to show pitfalls they have had. The spec itself is well written, except how can we collect leakage, or define leakage.

MR. MARTIN: At the present time we have a method which will beat anything known so far. We use a transfer barrier, a simple cylinder. The normal impulse that you normally apply to the packings in 5516 tests is simply being transmitted through a cylinder, with a piston in between the fluid and the system, and the fluid in contact with the packings.

We load up the piston or apply it to one end and load up the cylinder with oil and have it calibrated, and after the packing test is complete we force all the oil in the system out and measure it; and the difference, we assume, is leakage.

In a 50,000 cycle endurance test, which takes a couple of days to run, as a matter of fact, if there is any leakage you can detect it. It's not the best system, but it's given us rather consistent results.

MR. CHATTLER: Would this group accept that type of a test, for lack of anything better?

MR. KELLER: Do you measure these at the same temperature?

MR. MARTIN: Yes, at 300 degrees F.

Incidentally, all of our tests have been conducted at 300 degrees, not 275 degrees F.

MR. KELLER: I've noticed Frank Straus at Wright Field conducts packing tests one way; Douglas does it another way; and we do it another way. Frankly, I don't think any of us are doing the others very much good in reporting these packing tests, because we don't have a uniform method of making these tests.

I'm holding no brief for the method we use. I'm trying to get something uniform for the industry to be able to compare our data. I would like very much to have it the way we and the people at Douglas are doing it.

MEMBER: There are so many ways of making it. Maybe your way and WADC's way and Douglas' way will give you a liberal education.

MR. MIDDLETON: I thought it was good to try out different methods, because you may uncover weaknesses not covered by some other method of testing. If you have a standard method, it may be that everybody will overlook the same thing. It may show up in a particular application.

If you have bad packings, relatively speaking, they'll show up all about the same.

DR. MORETON: The original question, unless I'm very mistaken, the method we are using here in evaluating this is so close to the normal spec or the Wright Field method of testing, there isn't an arguable difference as far as our testing; is that correct Mr. Martin?

MR. MARTIN: Let's put it this way: If we ran simply 5516, we wouldn't be too sure whether that packing was good or not.

MR. CHATTLER: Are you speaking about a 300 degree test?

MR. MARTIN: Yes; or a 160 degree test. If we're trying to qualify packings for 160 and it is strictly a military spec test, we wouldn't be too certain.

MR. CHATTLER: You say MIL 5516 is not an adequate spec?

MR. MARTIN: We don't feel it is.

MR. CHATTLER: For the purposes of this spec, perhaps you can send your comments to Mr. Straus.

MR. MURPHY: I think you ought to have one base level test, and if you want to grant that, fine.

MR. GREEN: I think this is a very good item for discussion. I feel as Frank just said, that we should have a standard test as a base level test which we can all use. Then we'll have comparative data.

I'm sure that problems will come up which will be peculiar to some unusual packing operations and we will have to run other tests and maybe the base level test will have to be improved as we go along.

But I think now is a good time to throw ideas in and arrive at some means of testing which is more or less standard.

I think that one thing we should keep in mind in arriving at such a test is to arrive at a test as simple as possible from the standpoint of kinematics of the test rig and the hydraulic circuit, because we found in high temperature testing that we have so many breakdowns of various components it delays the work tremendously to fix up parts of the machine that fail.

I think we should pool our ideas on this thing and come up with something that would be acceptable to everybody, to do a good job.

MR. HILL: To get back to leakage measurement, I would seem to think that the fact that it's hard to measure leakage under these conditions is some indication that a small amount of leakage isn't important, therefore, any method which is the best that you can reasonably do, even though it's approximate, is plenty of good criterion.

There are two things about leakage: One is the amount of fluids you lose from the system; and the other thing is that it messes everything else up in the airplane which is usually more important. If it doesn't do that, possibly it can take more latitude.

MR. MARTIN: One thing I want to say, while we go through the motions of measuring leakage at high temperature and run tests which may or may not have significance, the evaluation of the results you get from the tests is more important.

We don't feel it's too important to collect leakage at high temperature. What's more important is the amount of leakage you get after temperature is reduced

after an endurance test of 50,000 cycles, and how much is the leakage at minus 65.

While you have leakage requirements, you have to evaluate which of the results are important and which results are not important.

MR. MURPHY: I want to comment similarly along what John's pointing out. What we want is the requirement for 275 limit, not just the leakage. What value is a life test run at 200 degrees or 275, if the 275 peak is not going to run 275 for the life test?

A complete evaluation, let's say, 275 top limit system temperature and a reasonable temperature specifically be written around that. I think it requires sub-committee work to arrive at something suitable to everybody.

MR. CHATTLER: We have a tolerance in our spec. What do you run it at?

MR. STRAUS: Seventy, 70,000 cycles and a temperature of 100 degrees. The new one should be something like this. Minus 65, so many cycles at room temperature; so many at top temperature; and so many cold.

MR. MURPHY: Why room temperature? Let's say you have a 275 peak. Your normal temperature involved will be higher than 110.

MR. STRAUS: When I say "room temperature", I mean standby.

MR. CHATTLER: He was mentioning, Frank, probably a temperature of 200 degrees where the packing will spend most of its operating time for the life test.

MR. MARTIN: Yesterday we discussed all these temperatures and to me they seemed to indicate the normal operating temperatures were running 50 degrees cooler than peak temperatures.

If we assume from the previous discussion on red oil that peak temperature is going to be 275, I don't know if we're still clear on that, but you mentioned in the final statement that 275 was a peak bulk temperature. I think what we're talking about is 275 period.

MR. CHATTLER: Correct.

MR. MARTIN: It might be out in the wing or tail someplace. If we have a 275 peak temperature and if we can assume that the difference between the peak temperature and normal operating temperature is 50 degrees, possibly the life tests should be conducted at that temperature with screening for leakage and packing characteristics after the endurance tests at other temperatures.

MR. STRAUS: That's something that has to be worked out.

MR. CHATTLER: Why not take your finished spec and send it to the people who want it and let them comment on it. Then you can start getting some ideas so that for the final coordinated spec, there won't be as much work.

MR. STRAUS: Right now physical property tests are bing run at 275 to see where they fall.

LT. KING: This has something to do with 5606, and is a mineral oil component anti-tack and a thickener. Now, in places where you have actuators drawn out and held for a long time, you may get evaporation; probably will get evaporation. Perhaps your maximum temperature will be dictated by that evaporation. That evaporation, if it's carried out to a point, may leave a fairly tacky surface which might effect the "O" rings.

MR. CHATTLER: Has anyone run into that?

MR. MIDDLETON: We've had some experiences which indicate that this soaking statically may be more injurious to the packing than continuous running. You can get different characteristics.

MR. CHATTLER: Mr. Martin, did you run any tests like that?

MR. MARTIN: Standby tests. We tested packings prior to test and also packing off the shelf.

DR. MORETON: One other suggestion, which is sure to lead to some controversy: In the past, when a problem of this nature has arisen, PRL in most cases have come up with a fluid which allowed you run the thing for test purposes.

In other words, hydrocarbon oil, with similar properties to 366, but doesn't have a thickener which is better in evaporation qualities, and didn't have this tacking that Lt. King mentions. If that could be used, it wouldn't have to be complicated at all. I'd like to hear any comments on the feasibility of that.

MR. CHATTLER: We don't do that now on our packing tests.

DR. MORETON: You're at a level where the composition problem would be brought into focus with 366. You may be reflecting something which is not typical of service conditions.

LT. KING: In line with what Dr. Moreton is talking about, Penn State did a lot of work on silicates and in all their lab tests it looked very, very good, but at our meetings there was an indication that we wanted 5606, no change, not a different spec with new materials, but with the old red oil.

DR. MORETON: My idea was to use it for endurance, where the problem of long soaks is leaving a tacking rod which would influence the packing, if it's not reflective of what they expect in service, then use an oil which has other characteristics.

MR. MIDDLETON: It's the effect of the heating on the packing. It's then started up again.

MR. WEINER: If I understand it, it is suggested that another oil, with better volatility properties, is suggested for certain test purposes. Red oil is dangerous because an oil not as volatile would not be subject to that evaporation. As Lt. King mentioned, it would also show different solvency characteristics. We wouldn't know what we're working on.

MR. CHATTLER: We've ruled out the test.

DR. KLAUS: An oil like that would be easy to formulate.

MR. CHATTLER: That takes care of our 275 packing specification. If anyone has any comments that you care to send to Frank, we would appreciate it.

<u>Now, packings for silicate ester based fluids</u>.

MR. BURNS: I'd like to make one comment regarding this temperature test for consideration.

We are at present testing at room temperatures for the major portion of their life, but operating systems 140, 160 up to 259, and we're deriving some satisfaction from that.

If we intend to impose hot box test cycle on every unit henceforth at these operating temperatures of 250 to 275, we're imposing a terrific expense on all our testing requirements and possibly be a screening test at high temperature we may be able to run most of our endurance cycle at a lower temperature.

If we operate 70 to 110 degrees and derive results up to 150, there is no reason why we can't do the same kind of testing on a large scale and derive information on temperatures of 250 to 275.

MR. CHATTLER: It's the screening tests that might be a problem. The question say for the 400 degree fluid, would be, whether it would be worthwhile trying to develop packings for the silicate ester type of fluid.

In other words, Mr. Bartholomew did not rule out rubber at 400 degrees, although at our last meeting he was skeptical on what they can do.

Do you think it would be warranted at this time to concentrate on packings for this type of fluid?

MR. WEINER: In my experience, what is called Park C293-70 rubber is nicely compatible. A year ago MLO 8200, in our exposure test, it conducted itself very well for attaining a maximum of 3.8 percent swell. In that standard test we have approximately 3-1/2 days exposure to five different conditions.

One condition is one hour at 400 degrees F and one-half hour at 500 degrees F and this rubber withstood it very well.

MR. BARTHOLOMEW: Let's say the rubber has existed very well for three hours at 550 which I think in some respects is quite an achievement. However, if you talk about low temperature, you're out in another ball park.

Today it would be questionable whether it would work. This whole program--Leo said at the last meeting I was skeptical--I would like to clarify that. I was asked whether a rubber meeting the requirements of an "O" ring and still in the operating range of minus 65 degrees F could be developed.

However, there seems to be some confusion over the validity that may go back to the same argument of the fluids a while ago. How many of the laboratory tests are truly indicative of service. It may take a new approach to a spec.

I will say this: We have rubber compounds now and hope to have much better ones in the near future which will exist in the silica esters or other types for prolonged periods. 70 hours up to 500 hours continuous immersion in the fluids, with temperature of 4 or 500 degrees. They will exist. They stay rubber like.

Some of these materials are flexible at minus 65 degrees F. Whether they will work in a hydraulic system I cannot predict. If they fail in the present screening tests of MIL-P-5315, I still wonder if they wouldn't work in many components of the hydraulic system. These are the things to be determined.

DR. MORETON: I have one word of caution in regard to the question of similarity. Our tests were all the presently available compounds including the acrolate types and the Buna-N types, neoprene types, some lastex. We have made exposure tests of the different forms of silicon containing materials.

Our data so far indicates that my pure base fluid with a skeletal structure of silicon has an effect of temporarily getting along with the high temperature in the fluid and subsequently loses some of its good properties.

I think a separate Wright Field report, or some other report, claimed that as a general rule silicates are poor plasticizers.

We took this into consideration with the fluids we have proposed and did something about it. As a result, while in some short term tests information is very limited, it appears at high temperatures one may see a very strong similarity between silicate ester base as we continue to increase the time or temperature we find verification of that which we are hunting for, which is a better compatibility with existing compounds.

We have been very badly bitten by the hydraulic engineers by Skydrol in its ability to get along with packings. We sacrificed a number of things to make OS45 get along with packings.

We would prefer that OS45 be judged with regard to the packings you want to use in that particular fluid and we would not recommend--in fact, we would recommend against using information from packings derived from tests in other silicate materials. Here's where the only major difference exists.

MR. CHATTLER: That's a new one.

MR. KELLER: At the suggestion of the rubbers lab, Mr. Bartholomew in particular, we had investigated this Hycar 21 sometime back and found that in addition to the poor low temperature properties, even though it existed in the fluids, the mechanical properties at any temperature were so poor it wasn't worth considering.

We have made tests in different silicate based fluids with a number of different types of packings and we will confirm Doug's statement on 0845, but even an end packing does exist very well. We are not basing our evaluation program on this fact, however.

We wish to leave the door open, in our own particular case, for other fluids if they turn up to be better.

Again on the recommendation of Mr. Bartholomew, we are doing most of our work on neoprene which is compatible on all known silicate fluids. I wish to point out, however, in the course of our testing we have surprised ourselves with the ability of packings to operate under high temperatures.

We think we have gone a long way in providing an answer to this problem. I do not want anyone to feel that we have a packing or are close to having a packing which can be used at high temperatures and subsequently be used at zero or below. I do not think we are there yet. We are probably not very close.

MR. CHATTLER: How good is it?

MR. KELLER: Bart can answer that.

MR. BARTHOLOMEW: It's flexible at minus 65 degrees F. It's hard to predict how well it will work in each application at low temperature. It's far better than the acrolene and better than the Buna-N.

MR. CHATTLER: Let's concentrate on the packings that will be good in the silicate ester fluids. This is going to be a major problem for the 400 degree system.

Item C, on Teflon rings, refers to the present dimensional controversy on Teflon rings. We expect to resolve this problem tomorrow at a special meeting with Douglas, Santa Monica, North American, Columbus, North American, Inglewood, the major contenders in this controversy and anyone else who desires to attend.

As I mentioned before, the packing tests, we have decided, will be run with Teflon back-up rings. I have just one other question to ask about the present Teflon rings.

Lockheed is claiming they're having trouble with the Teflon ring in the static seal application. Does anyone have any comments on static seal application of the present Teflon?

MEMBER: That was 6230 static seals.

MR. CHATTLER: I guess most people are using 6227. How about you, Mr. Bumb, are you using Teflon now?

MR. BUMB: Yes.

MR. CHATTLER: Have you been using 6230 applications?

MR. BUMB: Yes we have, but have not had too many failures as yet.

MR. MIDDLETON: We feel that the installation problem is bad. It's too hard to get these things into a cylinder or seal where you have a blind installation, where the ring has to be forced past the end of the cylinder or gland that screws in.

MR. CHATTLER: We found the same thing at Quonset, while converting some AD cylinders. They've recommended that we make the Teflon ring solid.

MR. MIDDLETON: With a scarfed cut?

MR. CHATTLER: Washer type.

MR. MIDDLETON: How do they get it in?

MR. CHATTLER: Internal gland, not external.

MR. MIDDLETON: There are many applications where the groove is on the male part.

MR. CHATTLER: You may have a cylinder end where you're using it as an external seal.

MR. MIDDLETON: We've had trouble with the 6227 sizes too.

MR. CHATTLER: Ralph, did you say you couldn't stay over until tomorrow? We're going to have the Teflon meeting tomorrow. If you can stay over, we might ask those people about their experiences.

Any other comments on packings?

MR. STRAUS: One correction I'd like to make that I think I may be responsible for. Page 4 of the minutes dated 6-7 October 1953: "Although the present standard "O" rings are supposed to be acceptable in the MLO-X fluid . . ." I think we can delete that because later tests show it definitely shrinks badly.

MR. CHATTLER: What do you want to say?

MR. STRAUS: I would say delete the whole paragraph and say: "It's very possible new packings will have to be developed in the MLO-X fluid."

MR. BARTHOLOMEW: I would like to point out that I have heard that most of the packing manufacturers are still reluctant to work very hard on some of these problems involving new fluids and particularly the high temperatures.

The thing I want to get across is, we at WADC, and all of the Services, have spent as much money on high temperature packing materials as has been spent on fluid developments.

We have quite a background available at the Field continually working on this problem. If any of you have questions or comments you care to make, I would welcome receiving them from you.

MR. CHATTLER: <u>Item C-1 Materials and Finishes is the next item on your agenda</u>.

On finishes--cadmium plate, tin plate, zinc plate--the question for these materials is the high temperature range. You will have to take precautions when you are designing your 275 degrees systems, to watch for those materials. Let's now have a discussion on these finishes.

Copper, for example in 5606. Frank, would you like to say something on that, what the effects of 5606 fluid are on copper at 275 degrees F.

DR. KLAUS: I can't speak for all 5606 fluids, but a typical 5606--several typical 5606 fluids that we have looked at--show no appreciable copper corrosion at the 350 degrees F. Copper corrosion does not start with incipient oxidation. In other words, you can have some oxidation before you get copper corrosion. You do get copper corrosion if you have severe oxidation.

MR. CHATTLER: Then for the purposes of these systems, until they have proven otherwise, we will assume that bronzes that have a semblance of copper in them may be acceptable for the system.

MR. MARTIN: We have run several tests in conjunction with this long-term discussion with Wright Field, and some typical aircraft forms of bronze that are used, as compared to pure copper at the 350 degree level, we find that the rate of attack on the typical aircraft materials is at least, at the worst, only half of that of pure copper; so that there is further evidence that it is more likely that the typical bronze will be fairly safe.

DR. KLAUS: I would like to endorse that statement. We have never found a bronze--that is worse than copper. They are all somewhat better than copper.

MR. CHATTLER: Does anyone have any questions on copper or copper alloys?

MR. ROTHGERY: I was wondering what the effect of MIL-O-6083 would be. What

would be the effect of any corrosion inhibitors; what effect they might have on copper.

MR. CHATTLER: I guess no one has any information on the effect of MIL-O-6083 preservative fluid on copper, WADC will conduct some tests in this respect.

The other item that we might discuss for a moment is aluminum alloys; and in aluminum alloys we are speaking primarily of 61ST, 52SO aluminum tubing, 24ST, 17ST and 14ST fittings and components. Should we conduct an investigation on No. 1, let's say 61ST and 52SO tubings, to see whether the fatigue characteristics of these materials decrease at 275 degrees F. I know they do decrease some.

Do we have comments from the Materials people present?

MR. MAGEE, WADC: There is evidence that fatigue characteristics of 61ST-6 at elevated temperature do go down. I think that all of you have the data on that which was done for Materials Laboratory by Armament Research. It's a very thick book, and it contains the complete data on these alloys, room temperature and elevated temperature--about ten thousand tests. That should be a guide that is fairly correct.

We know that 61ST is not as good an elevated temperature material as some of the others. 24ST fittings, 14ST fittings, when they are below the aging temperature of the material--that's 385 degrees--then they do exhibit good qualities. When they get above that, then you run into a problem.

I want to digress a moment and present to the people who are working with ultra-high temperatures an idea--this is not a new one--it's the idea of SAP, sintered aluminum powder, or, as Alcoa calls their product, APNP. That's pure aluminum. It's stable at whatever temperature you keep it. In other words, it is the only aluminum which does not decrease with time and temperature, because there is no alloy present.

For example, at 600 degrees, you could have a material which will hold 20,000 psi continuously. Materials Laboratory has work going on at the present time at Thompson Products to learn how to forge this, and they have made good progress. We weren't thinking of you people at the time that this was started; we were really thinking of the engine people with their aluminum blades, and of course their fatigue problem is far more critical than yours. However, I see no reason why it should not be ideal for you people that have to design to high temperatures, and if you think that there may be some merit in that for your future design. Maybe you will want to get in touch with Thompson Products, or somebody else, to forge a sample and try it for you, some fitting or something else.

I believe that BuAer has several projects on the materials, and WADC has another project on elevated temperature fatigue up to a 1000 degree. At 1000 degrees it's about 9,000 psi short-time temporal strength. These two fatigue values are relatively good.

This is something of promise, which when I listened to Mr. Keller with his presentation yesterday, I couldn't help but feel might be an aid to him and to the rest of you that may come into that category.

There are essentially four grades of this material: M255, which is approximately 5 percent oxide content, M257, which is approximately 7-8 percent oxide; the Swiss product which is approximately 11-12 percent oxide; and the M256, that's Alcoa's. That is from 13 to 17 percent oxide, and of course the properties increase with the amount of oxide present. The elevated temperature--let's say 600 degrees temperature--elongation of this pure aluminum alloy is 6 or 7 percent in 2 inches. It's less at elevated temperatures than it is at room temperature. However, that is not too much; maybe 9 percent at room temperature. Therefore, design criteria in that respect should not affect you too much.

I don't know if I've transgressed too far from the point at this time, but I thought it was worthwhile to bring up to you.

MR. CHATTLER: Thank you, Mr. Magee.

I think it probably would be warranted to conduct some impulse and vibration tests at 275 degrees F on the aluminum lines and fittings. We have scheduled to do some of this work this coming year. We will do the work with flared fittings and flare-less fittings.

Getting back to finishes, I believe that the cadmium plate was investigated in MIL-O-5606 fluid?

DR. KLAUS: Yes.

MR. CHATTLER: What were the results?

DR. KLAUS: Tests were conducted above and below 250 degrees; there is some indication that there was some 5606 fluid that corroded cadmium below 250 degrees. I don't know how easy or how difficult it is to eliminate cadmium plate, but on the basis of corrosion, it would be desirable if we were to eliminate it from the interior.

MR. MARTIN: How would you feel, Dr. Klaus, about this new nickel-process plate affair?

DR. KLAUS: I would guess that it would serve better than cadmium plate.

MR. MARTIN: It seemed very applicable when it was suggested.

MR. ROTHGERY: What is the problem--corrosion above 250 degrees, or is it a matter of the cadmium getting brittle, or which?

DR. KLAUS: It's corrosion. We can dissolve off the cadmium plate with most organic materials when they start to oxidize. That goes for diesters and mineral oil.

MR. CHATTLER: We had some experience with that, in hydrolube.

MR. ROTHGERY: We have done quite a bit of work at the Columbus plant; at the Inglewood plant also. We have investigated a number of nickel processes, and actually we found that corrosion-wise it is about as good as regular electro-plated nickel. However, the thing we have had against it has been the question of getting good adhesion. It requires extreme care in funneling this, and we've had trouble at times reproducing the same type of finish; that is, if we get one finish one time, the next time we will get another. It requires such close control over the bath that in effect it is also rather brittle, even after baking for fairly long periods. I think we ran into some problems with the hydraulic system.

MR. MIDDLETON: We had similar trouble with the electro-nickel, what testing was done with it, and in two or three cases now where we have used it, it has produced blisters or has blistered off, especially down in the bottom of grooves, places which are apparently hardest to get clean-surfaced; and the service gear has to be absolutely chemically clean and they don't seem to be able to do it.

MR. CHATTLER: I suppose many people are working with these nickel finishes. Maybe it will get to be a usable process if enough development work is performed on it. It is a reasonable replacement for chrome plating, because you don't leak air through the nickel as you will through the chrome plate.

MR. ROTHGERY: I think it's an expensive process, also.

DR. MORETON: We have had several specimens plated up for various reasons at different concerns that said they could do it, with equivalent results of those reported here; but recently they had the opportunity to review--I think the originator of the large-scale plate for this--in their new plant on the Coast. I might add that at first the chemists had gone to almost fantastic preparations to maintain the cleanliness of solution condition. Since, they had had obviously very wide experience compared to most of the others, it is equally obvious that they consider it important.

By the same token, most of the specimens that we have received from that source seem to be pretty good.

MR. ROTHGERY: We had some specimens that were good, and some we got that were not good. We found that a continual filtration of the solution is absolutely mandatory, for one thing. We ran into the problem of our pumps that were set up. We finally ended up by coating the inside of our pumps with Teflon, which worked very well.

MR. CHATTLER: The other two finishes in question are tin plate and zinc plate. Do you have any comments on that, Dr. Klaus?

DR. KLAUS: No.

LT. KING: I'll have some data later, on that.

MR. CHATTLER: Thus, summing up materials for 5606 at 275 degrees F:

1. We are going to run vibration impulse tests on aluminum fittings and tubings.
2. We are going to investigate further the tin plate and zinc plate finishes, and report on them.

Is there any other consideration that we should bring up at this time in regard to materials for the 275 degrees systems?

Before we close this subject let's talk about <u>corrosion resistance in our 275 degrees F 5606 system</u>.

We have been using the plain carbon steels and the high carbon steels with MIL-O-5606 and with 6083 as a preservative fluid. Now the major problems that we have, and this is a significant point, concern the component parts of plain carbon steels or high heat treat steels that actuate into the fluid and then out into the atmosphere. The subsequent atmospheric corrosion has been severe in hydrolube and moderate but unacceptable in MIL-O-5606. It would seem to me that this condition would become more critical when we operate at a higher temperature in MIL-O-5606.

Insofar as this point is concerned, this means only meeting the requirements of our present specifications, which apparently very few people have been meeting in the past. These conditions occur in sequence valves, pressure switches, single-acting cylinders, et cetera. This requirement will be rigidly enforced in the future by both the USAF and BuAer.

Now let's talk about corrosion resistance inside hydraulic components. As you all know we have had this subject under discussion for sometime and the Navy's theme has been and still is a more reliable component. The following is the Navy's reasons for requiring internal corrosion resistance:

1. Corrosion to a significant degree has been found in components that are in Navy stock rooms all over the world. Corrosion has been found in aircraft that were inactive awaiting delivery in pools for periods longer than 4 months.

2. A majority of the equipment returned from all parts of the world to overhaul bases in this country are discarded because of corrosion.

3. Corrosion has been found in components in prime contractor's plants awaiting production installation. Corrosion has been found to a small degree in components removed from active aircraft that have not been inactive.

4. Corrosion has been found in components in vendor's plants awaiting delivery to prime contractors.

In view of the above the Navy has gone ahead and is trying to get corrosion resistant materials or protective finishes on all of our components, even though we are using 5606. Maybe we have a little more of a problem in a carrier based airplane; I say this because we haven't quite concluded a joint Air Force and Navy agreement on making corrosion resistance a requirement. It would seem to me, though based on the above that it would be a very desirable requirement. I discussed this with the people at the A-6 Meeting; and certain people jumped up with both guns blazing, "How can you do it? We've been using 52100 steel for close tolerance valves, and 4130 and what-have-you. You can't use stainless steel with close tolerance valves; it's too soft, it will gall". But this is all talk of what has gone on in the past. This does not mean that we cannot start investigating materials, different types of materials, to achieve the construction of a component that under any handling condition, whether

it is in the contractor's plant or whether it is in service, that will insure us a component that is free from corrosion when we put it in the airplane.

They do an awful lot of repairing of airplanes. As a matter of fact, a good maintenance crew--and this is based on my experience on my trip overseas--out of 48 squadrons I found one squadron that I thought was really a sharp outfit. The reason I felt they were sharp was that every time they would have a failure of a component, whether it was due to corrosion or what-have-you, they would undertake a preventive maintenance program for checking this equipment on every other airplane, even though it may have occurred on only one or two aircraft. Their aircraft availability was very high. Of course, their preventive maintenance was also very high.

It was in this squadron that I really found this large volume of corrosion. I not only found it in the hydraulic system, I found it on a lot of engine parts, many fuel system parts, because they were using much equipment out of stock. They were changing equipment on their own schedule, where they thought there was a possibility of failure. On the components that we had for the Corsair airplanes, which were real old components, three, four or five years in stock, corrosion from that storage was really widespread; and they were supposedly stored with 6083--and it turned out they were. The squadrons were taking three, four and five units out of stock before they could find one that would work in an airplane.

This all gets to the point of saying that we need more reliable systems. Everybody says that. Everybody says: "We need two power controls, plus another safety, and what-have-you." Well, if we are going to increase that reliability, the elimination of the corrosion point, I feel, would be a considerable improvement; and the increased initial cost is just a drop in the bucket compared to what we are probably throwing away in corrosion of components. It really doesn't involve too much more money. It's just a matter of starting to see what types of materials and finishes can be used. Of course, this is a development process, but if we never start doing it, why we will never get it done.

I know some of you are thinking that unless we can sucessfully apply the corrosion resistant materials or protective finishes to our more complicated equipment that we may decrease the reliability of the component because of poor material combinations resulting in galling for slide valves increased operating forces for solenoids, extreme temperature binding, breaking of parts due to notch sensitivity, et cetera. All I can say in this regard is that we won't know until we try. I believe you all know that the materials people of BuAer are available at all times to discuss these problems with you.

This, of course, carries also into the different fluids that we get into. I don't know how good OS45 is as a storage fluid. I don't know if Monsanto or Douglas know that it is a good or bad long-time storage fluid. Do we need another preservative fluid for that fluid? We can eliminate the entire preservative problem by just selecting our materials accordingly.

So, for the record I want to say that I think we should do it, and that the end result will be a long time reliable unit.

MR. ROTHGERY: Are the Services doing anything about evaluating these corrosion-preventive materials? Sometimes there are a lot of erroneous conceptions about corrosion. The idea is, sometimes you put something in your radiator; your car is going to last for the next ten years without replenishing it or draining it out. Actually, the sources for some of the corrosion inhibitors are such that they are not good as far as quality control is concerned. I mean, we ran into some problems, I know. We were investigating hard aluminum and the corrosion inhibitors. We fooled around with some that were absolutely useless. There were claims being made for them. I wonder if the Services are doing anything about evaluating them.

MR. CHATTLER: There has been a lot of work done in evaluating fluids. How can you evaluate the material quality-wise, I don't know. All I do know is, that the chemists are mysterious people, and they can't give you a straight answer. I guess it's a tough problem to give a straight answer. In trying to analyze the hydrolubes I learned only that it is a problem I never could get a quantitative answer as to what happened to the fluid. It's just a big and complicated problem. I feel we all will be better off by building a system that from the materials standpoint we will minimize the effort that the chemists have to put into the fluid to do the job for us.

Does anyone want to make comments about this particular subject?

MR. STEFFEN, NORTHROP AIRCRAFT: I would like to ask you: Do you want a system that is absolutely protected against corrosion? Conceivably right now, you could make something that wouldn't corrode. New materials are available, if you want to pay for them, that won't corrode.

MR. CHATTLER: I don't know how such materials fit into all the different parts that we have to manufacture in the hydraulic system.

MR. STEFFEN: They don't go into all of them, but you can get more corrosion resistant materials, I would say, than we are using at the present time.

MR. CHATTLER: That is what I think we should try to do.

MR. STEFFEN: Regardless of cost?

MR. CHATTLER: I don't know what this means in cost. What material are you referring to?

MR. STEFFEN: 117-14 heat treated stainless, that I believe has good properties.

MR. MAGEE: Every thing is good except the stress.

MR. CHATTLER: That is your materials investigation program. One tough point is to determine the degree of corrosion resistance desired. This is still a big question mark, between the Air Force and the Navy. I don't think the 200-hour salt-spray test is the answer, perhaps the 360-hour 100 percent humidity test is the answer. I really don't know.

MR. STEFFEN: I think it would be good if you could define, more or less, what you would like to have in the way of material.

MR. CHATTLER: We're going to do that. We're going to try to select a list of materials that have corrosion resistant properties and for the moment say that these materials will be acceptable even though we know that some combinations may not be. As we discover these combinations we will rule them out for future design.

All I am trying to tell you is that this is something we should think about; we should start working on it, and we are going to try to get you to work on it by making at least one exchange of correspondence, where we will say, "What are you doing about getting more corrosion resistant materials in your airplanes?"

I think our whole high temperature program will be simplified if we do that; and let's try to do it.

Any other comments?

MR. CHATTLER: Now on the 400 degree materials, of course, we have more or less ruled out aluminum alloys. Mr. Magee of Wright Field has suggested some materials in the aluminum alloy field that may be useful. At the moment it seems that most people are using stainless steel, 4130 steel and 52100 steel.

The other material that I think we should be investigating is the titanium alloys. There we have the strength that we need.

As you know, we have a contract with Boeing, and we have one with Weatherhead. They are both investigating titanium fittings and tubing. The titanium fittings that I saw at Weatherhead looked very good to me. They hadn't gone through impulse or vibration tests yet, but it did machine very well.

Now, I don't know what titanium will do for control valves, or other components, but we certainly should look into it. There is no reason why we can't start working with it as soon as possible, even using it in our present systems--and not wait for the 400 degree systems.

MR. MAYHEW: Do they use roll threads?

MR. CHATTLER: They are regular, machined and roll threads, the same kinds they put on the present fittings.

MR. JACOBS, BUAER: Mr. Chairman, I might add, in your discussion of titanium you are confining your discussion to the tests that we have been running so far on hydraulic equipment; but in another area, the fastening field--the bolt and nuts field--we have run under experimental contract with the H. M. Harper Company, that all the normal production methods currently in use are acceptable with titanium.

One of the factors involved is the upsetting procedure, of course. I think they had to go into hot upsetting, but that does not always apply to the hydraulic components as we know them today. Roll threads, drilling, machining, forming, other machine shop practices that would enter into the construction of hydraulic parts, were investigated and the report of this contractual work is being made available, I would say to one hundred percent of the aircraft companies through the NASC Representatives. I suggest that you fellows get in touch with your NASC men when you get home and see whether those reports will be of any help to you.

MR. CHATTLER: There is much material available on titanium. I have a little book in my drawer right now in which there is listed several hundred titanium reports, the physical properties, forging and machining and what-have-you. You might get your materials people on the ball and start looking into it.

MR. JACOBS: The titanium fitting looks very much like the steel fitting, as far as finish is concerned, and all other outward appearances.

MR. METTEE: Bendix in their accumulator and acutating cylinder are going to try titanium.

MR. MAYHEW: Can you tell me what alloys you are using for those fittings in this contract, on the tubing and fitting contract? Were you able to bend it successfully, or were you trying flareless fittings to see what the results would be?

MR. CHATTLER: Mr. Mayhew, Mr. Jacobs is trying to get some figures on that. I think the last Boeing Report had some flaring data on the titanium tubing.

MR. JACOBS: To date, the information we received from either of these two contracts has been very meager. They've had delays in getting material and setting up for their initial experimental work, and as Mr. Chattler said, the last report from Boeing is the first real data that we have, and even that was rather skimpy. I think that it confined itself mainly to some flaring troubles that they had with the tubing.

We have nothing on any advanced tests, such as impulse or even static tests, I don't believe. We hope to disseminate that information from now on, rather that at the end of the contract. We will send it out intermittently as we get it from the contractors, rather than await the completion of the contract.

That's our present plan; it hasn't been finalized as yet, but we hope to do that.

You raised the question as to the alloys that were being investigated. I don't have the exact data before me, but I believe Weatherhead, on the fittings, is investigating the REM-CRU RC-130A. The tubing that Boeing is checking, I don't know. They are working with--well, the names of the companies are immaterial, because they each have various alloys. Unfortunately, I don't have that data right with me.

MR. MAYHEW: I would just like to add something: I had contracts with REM-CRU on tubing, and they say that they don't consider that they can make tubings with small wall thicknesses. Anything in the neighborhood of .035 to .065 is out of the question, as far as they are concerned. They say that the best they can do--excuse me, I am just talking about RC-130 alloy--is about 1/8 to 1/4 in wall thickness. That is very discouraging, as far as using it in place of stainless steel.

The reason I brought up this stainless fitting problem, I have also been made to understand that there is a sensitivity problem as far as titanium goes. That also predicated my question, whether they were roll threads or machine threads.

MR. WILLIAMS: We have fatigue tests on titanium bolts in comparison with

standard aircraft bolts, and we have found that they do have low fatigue properties compared to their ultimate strength as contrasted with steel, and we were getting head failures on them. The threads didn't fail; these are roll threads. We were working with 150 and 130.

MR. MAGEE: To me it looks as if rolling or any other forming titanium would have to be done warm. I don't see at the moment how you are going to get away from it, and of course that presents a problem. However, that is becoming a problem in all other metals, as you get the stronger alloys It may not be so difficult as the time that you want to use them.

MR. GREEN: We bought a few titanium parts several years ago. We had some check valves, shuttle valves and accumulators made of titanium, both titanium commercially pure and titanium alloys, and results on those parts were not encouraging. The cones of the check valves were badly beaten during the cycling test. The shuttle valve showed quite a bit of galling, and the shuttling pressure was quite erratic because of that. One of the accumulators failed on a proof test, due to what was analyzed to be an inclusion in the bowel of the accumulator.

I don't think any of these things should be taken to discourage us, but they are results of our initial work on titanium components.

We would like to proceed with this further, but our progress has been slow due to lack of manpower. One thing that has recently been suggested is that lithium may be a possibility for improving titanium with respect to its sliding characteristics. That is one idea that we hope to try.

MR. CHATTLER: Your experience, Mr. Keller? What kind of materials are you using?

MR. KELLER: We haven't tried titanium in anything, yet. We have tried 52100 stainless steel tubings, 4130/4140 blocks, and surprisingly enough, a lot of aluminum. The reason we are using aluminum is that on a number of commercially available components, particularly in the case of housing for pumps and valves of various types, the housings which are made of aluminum are made much thicker than is necessary for strength alone, in order to get sufficient rigidity. The thickness of material is way beyond what is required for strength, so that over quite a long period of time, the high temperature aluminum is still plenty strong, and this is true over quite a number of cycles up and down in temperature.

MR. CHATTLER: What temperature range?

MR. KELLER: Up to 400 degrees temperature range.

We are using quite a number of aluminum housings in our components, and our metallurgists tell us that we are quite safe in this. This isn't something we could seel too short.

MR. CHATTLER: Very interesting, Mr. Keller. Based on that experience I recommend that we look into the aluminum alloys for 400 degrees F.

MR. POLLARD: Along the same line, two or three of the component manufacturers that I have talked to have run similar tests on aluminum housed components; grading it down or increasing it proportionately to what they feel the aluminum will fall of at the high temperatures. They have indications that they will be able to use the metal in that way.

MR. CHATTLER: Did you test any of your aluminum units to really know whether you had the life the metallurgists say you had?

MR. KELLER: It so happened we did test them, but we tested them before the metallurgists had a chance to do all their slide-rule work, and we didn't run into trouble--and they confirmed that we shouldn't.

MR. PROMISEL: Which alloys are you talking about at this high temperature?

MR. KELLER: We aren't actually using particularly unusual materials at all; quite conventional.

MR. CHATTLER: 24-ST or 14ST?

MR. KELLER: I don't know what the aluminum housings are; what the particular alloy is. They are cast components. We use the material they buy. We don't know what the aluminum alloys are.

MR. PROMISEL: I don't know whether your test is short-time or long-time; but it should be long-time.

MR. KELLER: I say, I don't know for sure what these alloys are, but we are considering a minimum of two hours at elevated temperature, and usually we are talking about longer periods of time than that. In the course of that time, at any rate, we aren't getting into any trouble, according to what our metallurgists tell me.

MR. PROMISEL: Is two hours a significant number?

MR. KELLER: For one flight, sir, it is a significant number, even for aircraft, when you go up and then come down again. You go up and hold your high temperature, and then drop to the normal temperature; and then go up again. As long as at no time you hold it at high temperature for too long a period of time, you apparently are on fairly safe ground.

MR. PROMISEL: It's cumulative.

MR. KELLER: Apparently there is a number of cycles you go through.

MR. MAGEE: First of all, are you talking about casting alloys? 355, of course, is best at 300 degrees F. From there on there is a slight drop, so he might possibly be using housing of 355. 356 is not bad. On 24ST, where there is short-time use anticipated, some companies are under-aging it, either not giving artificial aids at all, which is a normal condition of 24ST or is they are using one, a 24ST-8 series, they are not aging it the length of time they normally would, and therefore the time in an air weapon would constitute part of that aging cycle--and they are overcoming the drop there.

In other words, they are actually going up in strength to the peak, and maybe just coming down slightly, if they overstep that time.

MR. CHATTLER: Of course, there still are many components made of aluminum alloys, as you all know. Some of the people have gone to the steels to make smaller components, but Mr. Keller's reference, Mr. Promisel, was to the fact that we have so much stress margin on some of our housings for control valves that thickness of the aluminum material will permit you to go to a higher temperature, and you wouldn't necessarily get a failure in a part that was stressed for a particular application.

MR. ROTHGERY: Batelle, in their Rand project a couple of years ago, did quite a bit of work on aluminum alloys--the effect of heat on them. In fact, as I recall, the report was something like that. There was a tremendous number of reports giving the effect on various types of aluminum alloys.

MR. CHATTLER: There is a lot of information available on the temperature characteristics of aluminum alloys.

Are you familiar with this Rand Project?

MR. PROMISEL: That was 1948, I believe.

MR. CHATTLER: You want to remember that you people are buying equipment from vendors who do not have material staffs, and these people are going to be dependent upon your survey of the materials in their particular components, as to whether or not you have the quality there that you want. You might take note of this particular point when you go out to buy your equipment.

You should also make available to your vendors the material information you have so that they can work on their own programs, and I suppose we can do that very nicely through our A-6 meetings, because about everybody and his brother are at them.

There is one more item, and that is springs; spring properties drop down with an increase in temperature. So far I only heard about inconel-X, on the springs. Is this an acceptable, across-the-board material for springs, or does it have some undesirable properties.

MR. KELLER: This is the first time we have actually used inconel springs. We made a number of tests on both the regular spring materials in relief valves, and some silicon steel spring materials; and the mechanical hysteresis curves on them were just terrible. We'd go up in temperature, the pressure would go way down; we dropped the temperature, and the pressure would go halfway up. It kept going in a loop like that. It probably would have stabilized off somewhere eventually, but it would take us too long to get to it.

This test we ran the other day on the Pantex relief valve with the inconel spring was the first test we had made with an inconel spring, and I would say the results were very, very striking. We just had no apparent fading of the crushing pressure at all over this wide range of temperature.

MR. POLLARD: Last fall, the ASME ran a series of tests on springs in New York. One of them, there was quite a bit of discussion on the effects of temperature. They mentioned the inconel, and there a couple of other alloys especially for high temperature springs. I can get that data and send it to you later on. (See Part I Republic)

MR. MIDDLETON: We have run some tests on some inconel-X springs fairly recently and through temperatures up to about 400 degrees, not specifically for hydraulic parts but for some other parts, and they worked out apparently very well. We haven't had any service experience on it, but the tests didn't cycle up and down. They didn't vary even a measurable amount going up to 400 degrees.

MR. CHATTLER: I understand there are several types of inconels.

MR. MIDDLETON: This was inconel-X we were using.

MR. SANFILIPPO, BUAER: Should we attempt to define what corrosion resistant steels are?

MR. CHATTLER: I don't think we can, at this meeting. You mean, attempt to establish some sort of suitable test for corrosion resistance.

MR. SANFILIPPO: Yes.

MR. CHATTLER: Well, I think it will probably be much easier to try to work something up first, and then let everybody shoot holes into it. From that we can arrive at some reasonable tests.

I guess, for the benefit of the Materials people, we probably should point out some of the problems involved in hydraulic system components. I thought maybe John Burns could give us some information on the tests that he has been running with stainless steel spools and sleeves, because many people have indicated a desire for such information.

MR. BURNS: We started this program about two years ago--more than that--trying to find a combination of a sleeve and a slide that would continue to do so over long periods of time. I think we have gone through every conceivable material combination there is, now; and we go along fine on one spool combination--say, choosing 431 heat-treat 124's and 45,000, experience, that is, and a chrome plated slide, just a 4130 chrome plated slide--and we have used that with quite a good deal of success on all of our conventional four-way control valves.

Typical applications are wing flap, landing gear valve, and so forth.

The next step was, we tried to make the slide also of stainless material. We have used 440's in conjunction with the 431, at differential hardnesses; that is, the 431 at 125 and the 440 stainless at Rockwell C-55 and C-52.

Of course, the reason for choosing the 440 for the slide material is because it's the easiest to fabricate. It's a ground diameter lans, only. We have been running into recent troubles with that, however. We find that the differential hardness is not the secret to the success of stainless steels in combination with each other.

We and Bertea have been trying 440's with 440, and 431 with 431, even at the same high heat-treat range, for both of those materials, and so far it boks good; but I venture to say, before we are done checking we will have one or two slide and sleeve combinations that will gall or cause difficulty.

One of the difficulties that seems to be an important factor is, if you have squeezedown, or if you have some pressure effect of squeeze on the slide--in one slide configuration and one valve configuration over another--you have considerably more difficulty, regardless of the combinations that you use.

We still have quite a few tests to go before we are sure of either of the 440-440 combination or the 431-431. Those two show the best promise so far.

One other thing we have considered is the nickel-plate. In fact, our A4D airplane started out with a consideration of using 4130 and 4140 pistons with chemical nickel-plate, in lieu of chrome plated piston rods; and we have run into a terrific amount of difficulty in consistency, as was implied by the two previous discussions. One of the things that we have discovered in using that type of material is the hardness of the material. You can't check it very easily in the production run of things.

The evidence that we found recently is that the hardness varies between batches from the same vendor. We tried four vendors, incidentally. The variations are very noticeable, and the variations in corrosion resistance by salt-spray tests are also very noticeable.

One of the ways of trying to attempt to get consistent hardness on the material--or on the coating--is to bake it, and these baking temperatures have been kind of an arbitrary thing. We haven't really decided yet what baking temperature should be used; anything from 350 degrees F to 500 degrees F. We found that the longer you bake it, the higher the temperature, the less corrosion resistance you get. In fact, we had one 500 degree baked specimen go completely red on us in eight hours' time, just by virtue of the side-by-side comparison of a sample not baked and one baked, showing that extreme variation. The other part went some 220 hours without any evidence of corrosion.

So chemical nickel is still a great doubt to us.

In two or three applications where we have had difficulty in finding a suitable corrosion resistant material combination, either from a bearing standpoing or something like that, we have reverted to the standard, conventional materials, even 52100 and just standard chrome-plate 4130, in contact with bare steel. This is a last resort for building airplanes.

MR. BREMER: We ran a series of tests on flareable materials also, a year or so ago, and came to the conclusion that the best combination was nitralloy sleeves and spools, which do not have quite as good corrosion resistance as some of the stainless materials, but it will always continue to slide. We operated some of these slides and sleeves with satisfactory results.

MR. CHATTLER: You weren't trying to put together corrosion resistant materials, were you? You were just trying to find a good combination?

MR. BREMER: Yes. We were also checking the corrosion resistance of the materials we were testing. I was going to say that we ran one set of valves in a hydraulic system contaminated with #600 carborundum, and they continued to run just as good as ever. In cleaning the system out and cleaning the valve out, we put the characteristics within our allowable range.

MR. CHATTLER: Mr. Weisskopf, do you want to report on your stainless steel?

MR. WEISSKOPF: We started about five or six months ago working with stainless steels for servo valve application. Corrosion resistance being one of our prime considerations at the time. we did go to 440-C stainless, and to date our work on

440-C on a range of C-62 to C-64 which we have received, they have proven completely satisfactory. They have not gone through extensive life-cycling tests--by that I mean, they have not gone two million cycles, in that neighborhood. We have run several hundred thousand cycles on them, and they have continued to function.

Several of the things we found out, though, was that cold stabilization on this is almost mandatory to getting the high case-hardness you want, when you get above C-60. Without stabilization, you have difficulty getting that. The diametrical expansion which the gentleman from Douglas mentioned--we have also found that. This has to be controlled fairly closely, in that a couple of tenths difference in clearance can make the difference between a working slide-valve and a sticking slide-valve; one which exhibits sticking characteristics.

MR. ROTHGERY: I don' know whether to bring this up or not, but we had some trouble with leakage on the landing gear structure recently that was chrome plated, and the reason I bring it up is the fact that we found out that the actual leakage was due to the fact--you are talking about using chrome plate for corrosion resistance --I am trying to point out that it's important that the pre-plating finish, before you put the chrome plating on, is good; because we were working with a finish without plating on it, and we found we were getting leakage because of the fact that--we were getting leakage through the chrome. If you do use chrome plate on a hydraulic component where you are going to have any type of pressure at all, you should use a good pre-plating finish before you put you chrome plate on it.

MR. CHATTLER: Thank you.

Is there anything else we should talk about on materials? Does anybody have anything he wants to say?

MR. PROMISEL: I'm sorry I missed what you said about titanium, but I gather that there wasn't too much said about it.

What I would especially like to get out of this group here now is a better definition of what their problems are, so we can begin working on some of them. These things take a long time to solve; they are not going to be solved in six months or a year, or even two years. It's not too soon to try to pinpoint some of the things that you run into from a hydraulic point of view.

I think titanium is one of the most promising materials for the hydraulic system components that you have for corrosion resistance plus strength, a combination that you can't beat with anything else available now, at elevated temperatures. I think you should get an aggressive program under way, rather than a passive program of merely testing a few things as they come along.

You people can define your problems; we will undertake to do something about them--but we cannot outguess you on them. So I would like to have something a little more positive and constructive come out of this than just an agreement that we will continue to look at titanium.

MR. CHATTLER: Of course, we are not quite in a position to get these people started on it. They have to do it mostly on their own initiative; however, the Services can institute a program. Of course, our corrosion resistance project might bring this into the picture a little faster.

Insofar as your question on the problems, maybe we could spend a few minutes on just talking about some of this.

MR. PROMISEL: Unless they want to consider this again in one of their subcommittees or panels, and prepare a coordinated statement of the kind of things that the Services and others should be working on. Even the vendors don't know completely what they should be furnishing their working crews.

MR. CHATTLER: I was referring to the functioning material combinations that you want; that is, why can't you use any materials for slide-valves, for example, especially the real close-tolerance slide-valves--or problems of that nature--poppets or what-have-you in the hydraulic system; and of course the fatigue problem is also a factor in the hydraulic system. Generally, I guess any one of the hydraulics people can sit down and think about what their problems have been and pinpoint some of them from a materials viewpoint.

We might just go around the room and maybe we can pick up some information; because we in this group here have no mechanism of really getting anything done yet. Maybe we could do that through one of our other committees.

MR. MIDDLETON: I have been interested in listening to the talk about slide valves, because I have had quite a little bit of experience with slide valves. Going back over that now, I think at one time or another all of these combinations you have been talking about--that is 440 and 431 and various other types of the so-called "hardenable" stainless variety, and such things as using your soft steels like 4130 and so on, chrome plating them, and nitralloy--and in general it seems to me that every time we have gotten into hardnesses that on less than about C-50 we get into trouble, even though we have one part hard and the other part soft. Some time or other, that doggone thing does not work; whereas, if you can keep both of them above C-50 and yet a stable material, it is truly stable at that hardness, it seems to work well. It seemed to keep on working, which is indicative that the average working conditions in the inside of your system are such that the part will resist damage due to whatever it encounters in the system, if they are that hard. If they are not that hard, sooner or later you find them hanging up, due to getting scratched or broken or what-have-you.

My experience has indicated, too, that in general we get along better if we have a homogeneous material or part, in preference to having something which just has a hard coat on it. Nitralloy comes into that category, too, because every now and then you find a case where the darn things do have stresses in them, brought out by the heat-treating process. It's a lot easier to control those stresses, in my past experience, if you can harden and stabilize the material as one homogenous material, rather than as two different kinds of material in one part.

I think that goes for poppets, too, as well as the slide valves.

MR. CHATTLER: Any other comments?

MR. FIELD: I think probably almost everybody knows more about this than I do, but we are making some servo control valves with clearances that are down in the millionths of an inch measurements, and we use sleeves of, say 52100, slide of 431, and they are both hardened; they are cold-stabilized--they have to be, you can't get anywhere in getting the things together--and it seems to work out pretty well. But our hardness is C-62 to C-65, in that neighborhood, and they are just about the same. Actually, with anything less than that, or by trying to skip the cold-stabilization, we get nowhere.

MR. MIDDLETON: One more point in regard to the soft materials like titanium and alloys is that, obviously, when you fit the parts that closely you have to lap them; and one big trouble that we have always run into in trying to do that is the tendency of those softer materials to charge with the harder materials, such that the locking materials cannot be removed, which means that we have a self-made lock there. That has always been one big difficulty in trying to use a softer material for those parts.

MR. IRWIN: On the same subject--of the aluminum usage in the slides and sleeves--the sharp corner on the lan of a slide, particularly in the servo valve, is a really critical measurement requirement, anyway; and the hard coat tends to chip off those corners very readily. The chrome plate does, too--which we don't use, incidentally.

MR. CHATTLER: You have to have a material that can be heat-treated to at least C-65, or thereabouts, in order to be able to make a satisfactory slide valve. Is that correct?

MR. MIDDLETON: C-50 metal, I would say.

MR. PROMISEL: Put a hard coat on top of it that doesn't chip.

MR. CHATTLER: Ralph, you were pointing out that unless the material is homogenous, you may get some undesirable stresses.

MR. MIDDLETON: I was talking about steel when I said that. I started to think about it in regard to steel. I don't know how it would work with an aluminum alloy, but I rather suspect that you would run into dimensional changes in the aluminum alloys. You would have to worry about heat.

MR. CHATTLER: In other words, you aren't going to have material that does not go with useable strength.

MR. WELLS, BELL AIRCRAFT CORP: Because of the tolerances on slide valves, it must be stable against growth.

MR. CHATTLER: Yes.

So this is one problem that the materials people must be cognizant of and consider when they want to supply us with new materials for our slide valves.

Now, can anyone think of any other requirements?

MR. BREMER: I don't think we should be tied down by any of these requirements too closely.

MR. CHATTLER: We're not tying anybody down. We're just trying to give the materials people guides so that when they suggest a material to us, they might know what some of the physical property requirements are. I know that we can generally say we want a material that is corrosion resistant, has good fatigue properties, is not notch sensitive, is easy to machine, can be heat treated to C-65 and at C-65 still retain its corrosion resistance, will not chip on the corners, et cetera.

Are there any other special cases that anybody can think of that fall into the category of the slide valves?

MR. BURNS: I would like to get an idea of anyone's experiences--you are talking about hydraulic components and troubles in a materials sense--how about finishes, external finishes of aluminum alloy products, such as housings or valves, and so forth?

You know, our experience has been a little bit enlightening on both shuttle valve and hydraulic lock valves, where the body of material is an extruded member or a forged member; and we're getting corrosion outside-in, obviously, because it is in a location susceptible to quite a bit of collection of salt-spray, and so forth, during carrier operations of the airplane, where a shuttle valve is located right on the wheel brake in the wheel well.

We have taken into consideration coatings, that is sulphuric acid anodize coatings on the material, zinc chromate, and a hydraulic fluid resistant paint coat on the outside, as an extra precaution, to keep any hydraulic fluid or lubricating oil from affecting the zinc chromate.

Could we have an idea of anybody else's experience or recommendation?

MR. CHATTLER: Yes, we could open that up for a few minutes' discussion. I don't mind telling you, this is a problem. Would you say in all of the airplanes, Ben?

MR. METTEE: We have had a lot of trouble with several different model aircraft.

MR. CHATTLER: We also have had stress corrosion failures of aluminum alloys components recently.

MR. METTEE: We have stress corrosion on all model airplanes.

MR. CHATTLER: There is corrosion from the outside-in; and corrosion in some cases from the inside-out. In one case, in one particular valve, there was corrosion originating from the back-up ring in the corner of a groove.

MR. MARTIN: There has been some problem in our plant, as I recall, of the corrosion that can occur to aluminum lines right in storage in the plant, where the interior line is all right, because it is capped off and sealed and has been treated; but the exterior apparently can get contaminated with dirt, which is all that is necessary to start corrosion; and I think--maybe Frank could correct me on this--but they worked on a new phosphate-type coating treatment which requires, as I recall, a subsequent bake, which looks very promising as a barrier-protection to corrosive influence from the outside, far more so than with any priming and other organic finishes.

I do not know the name of this. I don't recall the test work on it.

DR. MORETON: It has been done in our materials process group, and the last tests I saw on it were, in comparison with finishes now used, very promising for aluminum alloy lines.

MR. SHARP: I would like to ask, John, if you have been doing that long enough to find out whether it was working or not.

MR. BURNS: The finishing?

MR. SHARP: Yes.

MR. BURNS: Not really long enough; about six to eight months on most of the critical components, particularly those with which we had trouble; not enough service experience.

MR. ROTHGERY: Do you know why they went to sulphuric acid anodize? Why the regular chromic acid didn't work?

MR. BURNS: I can't elaborate on it; I'm sorry.

MR. CHATTLER: You selected sulphuric acid anodize because you got a thicker coat.

MR. BURNS: Yes.

MR. ROTHGERY: Isn't it more absorbent?

MR. BURNS: There is a depth of penetration in sulphuric anodize you don't get with chromic anodize.

MR. CHATTLER: I also did hear that sulphuric acid anodize will affect your fatigue properties more than chromic acid anodize. Maybe for the reason that it penetrated more.

MR. PROMISEL: Actually, on a chromic acid anodize, properly treated, the corrosion resistance can be equivalent to the sulphuric acid, not only talking about thickness, but corrosion protection. You get equivalent corrosion protection from a chromic anodize and a sulphuric anodize.

MR. BURNS: We were also concerned about handling. and scratching the total depth of the coating.

MR. SHARP: I wonder if that sulphuric acid anodize helps the abrasion resistance--the finish. Isn't it a good deal harder?

MR. MARTIN: It has to be tied down to the alloy, for both corrosion resistance and abrasion resistance.

MR. SHARP: That's the thing called hard anodize?

MR. BURNS: Sulphuric anodize is hard anodize, but it is a completely different process, with just the substitution that we are making of sulphuric, over and above chromic.

MR. SHARP: I was talking about the abrasion problem in service. You go to all of this trouble to protect your tubing.

MR. ROTHGERY: I was just going to say that the sulphuric acid anodize can be hard anodize, but it is operated at lower temperatures, among other things. We found that when it comes to corrosion protection on aluminum, use of this primer that the Navy has been using prior to the application of zinc chromate, gives very good corrosion protection.

MR. CHATTLER: Repeat that.

MR. ROTHGERY: We use mechanical film. I'm not just talking about hydraulic components. We have been using this primer, then applying over the primer regular zinc

chromate primer, and then our final finish. We get very good corrosion protection, very good adhesion. Adhesion is excellent.

MR. MIDDLETON: Isn't that a standard Navy spec?

MR. ROTHGERY: Yes, it is a standard Navy spec.

MR. MIDDLETON: That's a standard Navy finish we use, doing the same thing for protection.

MR. CHATTLER: Does the industry know that we are eliminating the requirement of not painting the last four inches of tubing in the airplane.

MR. SHARP: Now you want to paint it all the way up?

MR. CHATTLER: Now we paint it all the way up to the unit. If you remember, the reason the requirement was originated was because maintenance personnel would take tubing apart and then would get paint chips into the lines and fittings. Also painting the valves during the early stages of the War was a very sore point, because we were getting paint chipping off in the valves. It was a very definite problem, which was eliminated by eliminating the paint prior to installation.

MR. PROMISEL: The things that started the ball rolling in the reverse direction were reports and desires of at least one, and possibly more than one company concerning corrosion of those last four inches, and the nuisance of masking off and keeping it separated in repairing and disassembly, and lots of things of that sort.

We have had a request from a company to paint the whole piece of tubing, to eliminate both corrosion and some of the more practical aspects of it.

MR. MIDDLETON: I know you do have trouble along that line, getting corrosion in that last four inches.

MR. FERENS: From the description that you have given, it seems that it would be optional. From what you said about it, it sounded like it could be made optional in the spec, instead of saying "Thou shalt."

MR. PROMISEL: It seems to me that it is either good or bad. It is desirable that it should be painted.

MR. MIDDLETON: It is both good and bad.

MR. PROMISEL: That is true, but when you balance them out, you should come up with an answer either that it is good or that it is not good; that the advantages outweigh the disadvantages, or vice versa.

MR. BUMB: The end of tubing doesn't know which airplane it is on, most of the time.

MR. MIDDLETON: But the paint will get into the valve when the unit is taken off and put on again. That's where the trouble comes in. As long as the unit is not removed from the airplane, you have no trouble. It's all right.

MR. PROMISEL: As far as I am concerned, I am fifty-fifty on the proposition, so I am willing to listen to all the arguments either way.

MR. WEISSKOPF: It has been our practice at Grumman to prime the entire length of tubing as received; that is, anodized and primed to the entire length and cut to stock sizes or for tubing sizes, and I don't believe we have ever experienced any particular difficulty with paint flaking off tubing and getting into valves.

Likewise, valves are all primed that we buy--valves are primed prior to installation, and those particular installations where you are priming valves it takes care of your painting technique, cleaning and painting technique, to prevent getting paint or cleaner solvents in where you don't want them; but once you get that straightened out, I don't believe you will nave any particular difficulty. We've been doing it right along.

MR. MIDDLETON: Not the way we do it now. We paint it after it's in the airplane.

MR. CHATTLER: Well, if it's painted after it's put in the airplane, then when you crack the fitting, paint chips will get into the system unless you have a type of paint that does not chip.

MR. WEISSKOPF: You're talking about painting after installing in the airplane?

MR. CHATTLER: Yes. I don't know what the general practice is.

MR. MIDDLETON: What we do now is paint after installation in the airplane. We mask off the fitting and the last four inches, I believe it is, of the tube. I don't think the last four inches is particularly a critical dimension, however. It's only that portion which is right back of the metal sleeve which would be important, where you'd be apt to chip the paint off the tube. If it is entirely painted, when you have a coating of paint which is going to be broken when you disassemble the valve, and that's where you get into trouble.

MR. WEISSKOPF: We have never experienced that.

MR. CHATTLER: You don't paint after installation, is that correct?

MR. WEISSKOPF: No.

MR. CHATTLER: You have it primed and painted before you install?

MR. WEISSKOPF: Right.

MR. MIDDLETON: The metal sleeve is not painted.

MR. DETWEILLER: Part of the tube goes down into the fitting and is really inside the system.

MR. SHARP: It might make some difference where your tubing is located and what kind of a system you use it on. The control systems we are using, with the little clearance in valves, the system won't tolerate it; whereas in some other instances with less tolerance, it might tolerate it.

MR. CHATTLER: I will recommend that we do some more surveying before we finally let this requirement go through.

MR. MIDDLETON: Why not, as another suggestion, say "Paint everything except the nut and sleeve at the end of the tubing"? In other words, eliminate the "four inches," and just leave the "nut and sleeve" bare, because that is the point that you get chipped off.

MR. CHATTLER: The next item is pumps, Item D. Now, on the remaining items, all I am going to do is tell you what the Air Force and Navy development programs are, and you will be free to comment, or if you know of anyone else that is doing work on high temperature components, if you will fill us in on that we might be able to get a complete report of everything that is under development for high temperature.

Break out your copy of the minutes of the 6 and 7 October WADC-BUAER Meeting, dated 23 October 1953. It contains a list of most of the equipment that we are working on. Power Plant Laboratory has a list of contracts, and it might be appropriate at this time to call on Mr. Maguire to outline his high temperature pump development contracts and also possibly say a few words on the high temperature pump testing that he has been conducting at the field.

MR. MAGUIRE: On this conference report, on page 6, I will outline the present status of the contracts and the PR's that are presently under development at the Power Plant Laboratory:

Item 1,a - The displacement high temperature pump at the New York Air Brake Company is coming along extremely well. At the present time they have the pump fabricated. They have asked and received permission to run some side studies of actual high temperature testing on one of their standard, modified pumps to gain high temperature testing experience before they actually test the research and development pump.

The sideline testing is being conducted with OS-45 hydraulic fluid.

To date, they have run several hundred hours of testing, and have had excellent results. The actual contract hydraulic pump tests will be conducted with Cal Research 8200 hydraulic fluid.

Item 1,b - The 5000 lb. 550 degrees F pump, which is going to be a long-life pump, at least 500 hours; a contract has been signed at Wright Field and has been forwarded to Bendix for signature. We expect to get this program under way in the very near future, and expect to have some concrete results in approximately two years.

Item 1,c - This is a variable displacement pump, short-life, for use in a metal application. This Purchase Request is in contract form, and contracts have been signed and work has been started. One contract is with the Bendix Aviation Corporation at Hamilton. The progress on the contract to date is not too far along, because they just recently signed the contract.

We have a second contract for the same item with Pesco. The progress on that is also none at the present time, as the contract was just recently signed. We expect to get final articles and satisfactory tests in approximately one year.

Item 1,d - A short-life high temperature hydraulic motor, is also for missile applications and is designed as a pair with the short-life high temperature pumps. That program also is with Bendix, and they have the contract at the present time for signature.

Item 1,e - Since this last conference this project has been canceled. The main reason was lack of Air Force funds.

Our program at the Laboratory, which we have been running for close to a year now, falls basically into three categories. We are running high temperature tests on standard pumps with 5606 oil up to 300 degrees F. In that same program we have run Cal Research oil 5277, and we are at the present time running MLO 8200.

We also have a program of a 553 pump with Mr. Keller, where we are attempting to satisfy his requirement for his particular application. I will briefly give you the progress that has been made on all of these programs.

The program with MIL-O-5606; we have run a Vickers fixed displacement pump a total of 560 hours, with 133 hours at 100 degrees F, 167 hours at 180 degrees F, and 167 hours at 250 degrees F. In operation, it was considered satisfactory. We have not taken the laboratory data and actually broken it down to curves where I can quote efficiencies, loss of flow, and such items as that. Examination of the pump after the test showed that the wear of the pump parts were very satisfactory up to 250 degrees F.

We ran two Vickers pumps at 350 degrees F with Cal Research fluid 52742. These were variable displacement pumps, and one pump lasted a total of 16 hours; the other pump lasted a total of 35 hours. Both were complete pump failures. The pumps were for all practical purposes completely worn out. The universal joints had worn completely, and such items as that.

I noticed in the Penn State Report that was handed out yesterday, that some Vickers pumps were tested at 300 degrees F, and they got approximately 208 hours on. So based upon that and based upon the tests that I have run at 250 degrees and 350 degrees F on Vickers pumps, the present indication is that somewhere between 300 and 350 degrees F, the performance characteristics of the pump fall off to practically nothing. Just where the point is, I don't know.

We also have run New York Air Brake pump, series 67WE300, using the Cal Research fluid. We ran that at 350 degrees F, and we got 60 hours on the pump. This 60 hours is at 350 degrees F. We did not record the time it took from ambient to 350 degrees F. No pump failures occurred. The pump was in good shape at the end of that time, and we have since torn the pump down and replaced all of the "O" rings and as of the first of the week they were just starting up for more tests on that same pump. This time we will use the Cal Research 8200 fluid, from the 60 hour portion on.

However, we had to modify the New York Air Brake pump to make it work. I

replaced the leather back-up rings in the head of the pump with metal rings of the same size and the same thickness. That substitution to date has allowed us to run--as you can see here--some 60 hours on standard "O" rings. Prior to that, I was fortunate to get 3 or 4 hours' running time, with the original "O" ring application.

On our 550 degrees F test that I have been running we have run Vickers pumps, both variable and fixed; New York Air Brake pumps; Dennison, Hamilton Standard and Bendix pumps. In this program we tested to a temperature of 550 degrees F, and going from ambient to 550 degrees in approximately one hour. The results of the test are as follows:

On the Vickers, a variable displacement pump and all those pumps for the AA3507L2 used on the F-86 airplane--the average time per test turned out to be 4.93 hours. The average time over 500 degrees F inlet temperature was 2.84 hours. The best run at 550 degrees F was 2.33 hours; that is, it ran 2.33 hours after you reached 550 degrees F.

On the New York Air Brake pumps that we ran--this I might point out constitutes around 21 or 22 pumps tested. That's total pumps. The New York Air Brake pumps ran an average time of 2.58 hours. The average time above 400 degrees F was three-quarters of an hour. Average time over 500 degrees F was zero hours; and of course the average time over 550 degrees was also zero hours.

The Dennision pumps that we ran gave us no useable data. I have a figure here of average time per test of one-quarter of an hour.

The Hamilton Standard pumps, of which we have run one, have given us no useable data.

The Bendix pump, of which I have run one, has given us no usable data to date.

All three of those companies will have to do some work on their basic pumps before we can get any data.

The Vickers constant displacement pump--I'll add that as a final item--the average time per test was 4.25 hours. Ther average time above 500 degrees F was 1.68 hours. The best run at 550 degrees F was 3.33 hours.

I would like to point out at this time some of the general items that we found, and especially on the 550 degrees F tests, some of the major problems. One is in the variable displacement pump. Considerable work is going to have to be done with the pump to compensate the controls, especially in the springs and the expansion of the housing, with the increase in temperature. That is especially true with the Vickers pump and the Dennison pump.

The loss of flow as the temperature increased was in some instances, on some pumps, quite high. I think I can quote you a figure on a Vickers 3911 pump which started out with flow of about 8-1/2 gallons. By the time it reached 550 degrees F, the flow went down to about six gallons and stayed at six gallons for a couple of hours. It again dropped at the end of that time to approximately four gallons, 4-1/4 gallons, then stayed constant till failure of the pump.

I just brought that up to point out that we are going to have a problem, especially with standard pumps, in actual loss of flow or horsepower due to the temperature rise. That varies with the manufacturer of the pump.

The New York Air Brake present production pumps as a whole are not satisfactory at high temperature. That includes all of their models, including their new models, the 66 series, because of the differential expansion of the piston with the piston block.

The pumps as a whole will freeze up and seize somewhere between 300 degrees F and 350 degrees F. However, I did get one pump on their 67 series that ran several hours. In fact, it ran about 3-1/2 hours, with a maximum temperature of around 480 degrees F. Evidently, the clearances of the piston and piston block on that particular pump were large enough to get past the point of freezing. That pump number was No. 67WE300 series.

Of that series, I tested four pumps. One pump lasted, as I said, about

3-1/2 hours; the other three seized and failed somewhere between 300 degrees F and 350 degrees F.

MR. PAGLIARINI, NAMC: Can you tell us the operating pressure of these tests?

MR. MAGUIRE: All our tests to date have been done with 3000 lb. pumps. We did run a Vickers 3918 3000 lb. pump at 1500 psi, basically because the test stand that we do have would not operate the pump at full speed, full pressure. On that pump, by the way, we got a total of seven hours of test time on it. That was at 1500 psi.

MR. PAGLIARINI: Can you tell what metal you were using for back-up in the New York Air Brake Pump?

MR. MAGUIRE: I used just plain aluminum. I don't know the exact type. It was a piece of stock that we had around. We hacked out some back-up rings out of it.

MR. METTEE: What was the inlet pressure on the suction line?

MR. MAGUIRE: All the tests were run at 40 psi on the inlet, with a pressure over the fluid, except the 67 series New York Air Brake pumps, which were run at 10 psi.

MR. DETWEILLER: The metal back-ups were solid, or strips?

MR. MAGUIRE: Solid.

MR. SANFILIPPO: New York Air Brake has indicated that they can modify their pumps to make them suitable for high temperature. Have they submitted any to you?

MR. MAGUIRE: Yes, they can. They are testing a pump right now, and it is coming along extremely well. In fact, to give New York Air Brake a plug--if it sounds like that--they are by far the leaders in the field of high temperature pumps. They are the only company I know that actually has a high temperature pump under test, and that has had several hundred hours of test time. They are leading the field right now, and are doing an exceptionally fine job.

MR. BUMB: In that last series of tests that you describe, what fluid were you using?

MR. MAGUIRE: On all the 550 degrees F tests we are using PRL-5-3961; MIL-O-5606, Cal Research 8200, and Penn State 3161 will all be used. We have no plans to date to test any other fluid.

MR. BOLZ, REPUBLIC AVIATION: Were the pumps running at full flow all the time, or cycled?

MR. MAGUIRE: We were cycling the flows on the 550 degrees tests. As a general rule, the breakdown was 300 degrees F, 350 degrees F tests. Today we are not cycling them, but the 350 degrees tests were all cycled at different flows at different pressure.

MR. CHATTLER: Any other questions?

MR. POLLARD: This is not a question; just for interest. New York Air Brake ran a test with some 7808, around 300 degrees F. The pump broke down after a short time. They found that copper has been stripped out of the block in one place and deposited all over their pistons, which seized up--actually copper-plated.

MR. CHATTLER: Thank you.

As far as the Navy is concerned, we have one contract with Sundstrand to develop a six gpm 3000 psi 3750 rpm range, 400 degrees F pump. Mr. Mettee will report on that development.

MR. METTEE: That pump is on the board now, and we expect to have it completed about the end of the year.

MR. CHATTLER: Any other comments or questions on pumps? Or is there anything that you think we should be doing that we are not doing.

MR. MAGUIRE: I would like to find out, if possible, what the aircraft companies are doing at the present time for high temperature tests on pumps, and what they plan to do in the future--if possible.

MR. CHATTLER: Let's briefly ask the people around the table if they are running any tests.

Mr. Martin, Douglas Santa Monica, are you running any pump tests at any elevated temperatures?

MR. MARTIN: None that could be so defined. We are using pumps in developing fluids, but not to develop pumps.

MR. CHATTLER: Lockheed.

MR. MIDDLETON: No, we are not. We are sitting here with our fingers crossed very tightly. We have some Vickers pumps installed, and we are afraid they're going to get over-heated when they start flying the airplanes; but having seen the results in some of the tests that have been run, we didn't know exactly where to start. So we have been sitting back waiting to see what development might come up that we might be able to seize on and carry on from there.

Right at this moment we haven't done any high temperature tests on our pumps.

MR. CHATTLER: Mr. Pollard, Republic.

MR. POLLARD: We have a New York Air Brake 66WA300 that we are going to be testing soon in our high temperature laboratory. We are starting to run it around 300 degrees F. We don't have any data on it yet, because we haven't started testing.

They made one minor modification to compensate for difference in viscosity of fluid. Aside from that, it's standard.

MR. CHATTLER: You don't want to forget that we have selected two temperature ranges, 275 degrees F and 400 degrees F. So I would appreciate if you would try to concentrate your testing to those temperature ranges.

MR. POLLARD: We will be testing at other temperatures, I assure you.

MR. BLAND: We have two Vickers 3911 and 3913 variable delivery pumps that we will be running the first of the 560-hour test at 200 degrees F. That with impulsed full-flow cycle.

MR. BUMB, NORTH AMERICAN, INGLEWOOD: Well, as I outlined yesterday, we have run about fifteen different pumps, I believe; but our principal objective there was to try to evaluate fluid with pumps, rather than pumps with fluid, in a sense. Those have been run at 300 degrees F, by and large; in other words, there's been the 275 degrees F idea, rather than the 400 degrees F idea.

New York Air Brake accepted a purchase order from us for 400 degrees F pumps, they are the only company that will take a purchase order for us for any kind of a high temperature pump. These pumps will be delivered in about six months from now.

In the meantime, we are running some more Vickers variable deliveries at 300 degrees F.

MR. CHATTLER: Mr. Klevin.

MR. KLEVIN: We are releasing specifications at this time for 10 g.p.m. 350 degree pumps, and our intention is to be testing in about six months on that.

MR. KELLER, NORTH AMERICAN, DOWNEY: We have just received two pumps from New York Air Brake which have a special hot-and-cold cycle delivered to the piston clock in an attempt to stabilize it, so that the dimension won't change at 350 degrees F. We haven't run those. We will, shortly.

In addition to that, we have two pumps on order from Vickers, and they have informally talked a phenomenal number of hours--350 degrees F--for these pumps. I would hesitate to quote the number of hours.

MR. CHATTLER: Mr. Sharp and Mr. Field, Convair San Diego?

. . . No data . . .

MR. CHATTLER: Mr. Bremer, Boeing Airplane Company?

MR. BREMER: We have been maintaining a log on our pumps, as I outlined yesterday, just to see how the pump manufacturers produced. We're continually buying new ones that keep our high temperature program going. We have both New York Air Brake and Vickers on order right now. They are both six gallon pumps at 1500 rpm.

We have also been hoping to find a commercial pump that we could use just to keep our high temperature program going, and I'd be interested in knowing if anyone else in the room has been looking along those lines, or if they have found a commercial pump that is satisfactory.

MR. POLLARD: Dennison makes a conversion for their standard pump which they will guar[illegible]e at 300 degrees F.

MR. MARTIN: We have one.

MR. BREMER: Do you have compensator control on your handwheel?

MR. MARTIN: No. It's strictly a fixed displacement pump, and we run it through the system by-passes.

MR. MAYHEW: I just wanted to add to what Mr. Pollard said about the pump. As far as the temperatures go, we had anticipated that you would have all those troubles with the pumps, so we had planned on putting a heat exchanger in before you get to the pump; and we had been regulating it down to 300 degrees F.

However, some new requirements have come up in the past few months, and we may have to test it at much higher temperatures. We intend to be testing on our own, and tests have already been run on New York Air Brake pumps with this Texas fluid that have been done by New York Air Brake; but our test chamber will be ready in another couple of months, which is when we will be doing our own testing.

MR. BURNS, DOUGLAS AIRCRAFT, EL SEGUNDO: No tests at El Segundo.

MR. CHATTLER: Does that give you a good picture, Mac?

MR. MAGUIRE: I have only one more point to bring out. I will take the pump companies' side right now, in that the companies are getting into binds. The aircraft companies are coming for pumps, and coming through with their special-type fluids. I open that program up again. Especially at the New York Air Brake Company right now they have orders for high temperature pumps or inquiries, and they have eight or nine different fluids that they have been requested to test the pumps in. At the present time, their laboratory equipment cannot possibly hope to stand a program with a large amount of different fluids, and I would urge that the aircraft companies, if possible, do as much of this high temperature testing of special fluids in their own companies as possible, and not try to get the pump companies to do it, because they are reaching the point where they cannot possibly do a lot of testing with a lot of different fluids.

They have enough problems to try to solve the high temperature problem, using only one fluid. That is one reason why I would have liked to see a standard hydraulic fluid established as soon as possible. It would solve the pump problem of these pump manufacturers.

MR. CHATTLER: I would say, Mac, that it appears that most of the testing in the next year will probably be done with OS-45 and 8200.

MR. MAGUIRE: Very probably.

If fluids are held, say, to two fluids, that will ease a lot of the problems; and one other point, the pump companies do have the same problems with seals that the aircraft companies have. You need pumps to test seals, but the pump company has to solve the seal problem before they can give you the pump.

MR. CHATTLER: Well, they have to test the seals.

MR. MAGUIRE: So this whole program is inter-related. The pumps, fluids, and seals have to come along at just about the same time.

Now, I have told all of the pump companies to design all of the seals in the pump that they can, and to use anything and everything that will work and not worry about a standardization of high temperature seals yet. I hope that way that we will get the pumps early enough so that you can test your systems, and eventually we will have to resort to standard high temperature seals and pumps; but for the present, we are trying to get you the pumps for high temperature first, and worry about standardization later.

MR. CHATTLER: To sum up and categorize the pump program: For the 275 degrees F system, I believe from what has been reported we are probably in reasonably good shape for pumps.

For the 400 degree program, there are a number of pumps under development, and this work, plus the impetus of the aircraft people who are gathered here--we will certainly get some pumps within a year.

The next item is directional control valves. First, solenoid operated; WADC has a contract with the Parker Appliances Company for a 600 degree solenoid control valve. This control valve, as I understand it, was developed for laboratory test equipment. However, they had aircraft process design in mind when they developed it.

I also understand that they are not testing it; that Wright Field will be testing the unit. Second, manual control valve; strangely enough this Navy bid contract also went to Parker Appliance Company. The valve is the 3000 psi, 6 gpm for -65 degrees F to +400 degrees F. In this contract, Parker tests the valve before we get it.

Are there any comments on control valves?

I presume that our one problem with 275 degree systems is going to be the solenoid for our solenoid control valves. Have the companies that have been working at high temperatures run into that problem?

MR. KELLER: We've had some amazing success with electrical equipment by using high temperature core materials of various sorts and winding the solenoids out of wire which has a suroc insulation and/or glass insulation. We have received a number of solenoid valves to operate pretty regularly at 400 degrees F; and we had one electrical item, which was not a solenoid valve but probably something which would be more complex. It was a heat transformer type electrical pickup for a servo system, and we operated that thing for about 10 hours at 700 degrees F.

It seems it is possible to get electrical equipment that operates at 400 degrees F levels. I don't think there has been enough work done on it yet to really be very secure, but it doesn't look like an insuperable task.

MR. BUMB: I believe for the past three years we have required in our valves what we have called 250 degrees F valves, as far as your solenoid is concerned. However, it isn't a very comprehensive test that has to be made. In other words, our requirements have been to promptly warm the unit to 160 degrees F--a larger unit to stand at 160 degrees F for six hours--and then raise the temperature to 250 degrees F, allowing you to stabilize and operate then under those conditions.

In other words, it is not a profound 250 degrees F test, but it does approach the problem. We have had no particular trouble.

MR. POLLARD: In connection with our tests, we are getting, or have, the following:

We are reworking models in 25750 for the solenoid valves, using special electrical insulation for Bendix 551, 590-0-1 solenoid four-way and a 457850-1.

Then we are also testing Midwestern Geophysical gyrovalve Model 3 and amplifier.

MR. CHATTLER: Up to what temperature?

MR. POLLARD: 500 degrees F, and so on.

MR. CHATTLER: In general, we should all start specifying these higher temperatures of electrical solenoid valves, and I dare say that you probably should put some margin on it to be sure that we have something that will work at 275 degrees F--for that range--and for 400 degrees F, you'd better consider at least a 50 degrees F margin.

Now, in the manual control valves or servo valves--Mr. Sharp, do you have a comment on that?

MR. SHARP: Yes, Leo.

On high performance control system, servo system, we experienced dynamic instability as we increased our temperatures to 200 degrees or 225 degrees F range. The rsults were really consistent. We could duplicate the range any time we wanted, and resolved it merely by--I guess we got above the temperatures where we were operating; we reduced the temperature in the system, and finally got it stable throughout its operating range.

I am curious to know if anybody else had any correlation with temperature and dynamic instability in servo systems.

MR. MIDDLETON: Yes, We use a special kind of dampers; in other words, that were relatively insensitive to temperature, and so far we have our fingers crossed. It seems to work all right. That's only a mockup test. We haven't tried it in the airplanes.

MR. SHARP: I'm not sure whether it's in the valves, or whether it's a function of the whole servo loop.

MR. MIDDLETON: I think the whole servo loop enters into it.

MR. POLLARD: Yes. We have gotten some greater indications of instability in valves at elevated temperatures. We are running some tests now which should give us further information on that.

MR. CHATTLER: That takes care of control valves. I guess any other valves will follow the pattern of the control valves. Their requirements are usually less stringent than the control valves.

In case I haven't mentioned it, the whole purpose of our program is:

a. To stimulate developments.
b. To test components for our information and for the preparation of specifications.
c. To test them in a complete system so we will be able to comment intelligently when you submit your schematic diagrams on high temperature systems.

<u>The next item is relief valves.</u> The Navy has a contract with Pantex which most of you know about for a 3000 psi 400 degrees F valve. I believe Mr. Keller is using some of these, and we gave six of them to the Air Force without the packings, since this is still the problem in the valve.

MR. KELLER: We have the neoprene-W in our Pantex valves. We have three static seals and one sliding seal, all out of neoprene-W. It seems to work all right.

MR. CHATTLER: Of course you all know that the spring is an issue in the material problem, and I understand that inconel-X springs are being used to solve this problem. Are there any other foreseeable problems in the relief valve?

Mr. Keller, in your tests of the relief valve, have you found cracking and reseating pressures follow the general pattern of the other relief valves at lower temperatures?

MR. KELLER: We have just tested two types of relief valves with and without inconel springs, and the ones without the inconel springs are just terrible at high temperatures; and there is one we have tested with an inconel spring that apparently was not affected to any marked degree by any change of temperature, so far as we were able to see. We soaked it overnight at -65 degrees F and got a 3450 crack; and then took it up to 500 degrees F and soaked it for an hour and a half and got 3425 crack. It doesn't appear that we had any significant effect on this valve from temperature; whereas with all these ordinary spring valves that we have worked with, we've had all kinds of terrible reactions.

MR. CHATTLER: In the 275 degrees F temperature range, do you think we should go to inconel springs?

MR. POLLARD: We made one test run that included 275 degrees F, and as I recall, we had some history of trouble, but I don't remember the numbers, and I don't recall whether it would be enough to give trouble or not. I suggest that you have someone test that. That is a simple sort of test to make

MR. MIDDLETON: Wouldn't it be possible to make it 275 degrees F by just reducing the stress in the springs. It makes a bigger valve, but you can work the springs to high working stresses under normal conditions, just by reducing that stress by some fairly reasonable margin should be ablt to go to 275 degrees F.

MR. POLLARD: Well, probably find that the 275 music wire won't be much good for springs. We probably will have to go to inconel or other alloy steels.

I wonder if there is any noticeable tendency of these wires to squeal more at the higher temperatures, more tendency of instability. We noticed with 5506 a tendency of a couple of valves in the lot a couple of weeks ago to squeal more with the oil temperature around 225 degrees F, valves that did not squeal at lower temperature, and I wondered if that had been noticed on any of these valves.

MR. KELLER: We didn't run enough tests to say that we wouldn't run into squealing. I am talking of a total of maybe half a dozen different test runs, and on none of these have we noticed any squealing.

MR. BUMB: I think the falling off in pressure was due to changing elasticity and is not due to the operating stress of the spring.

MR. KELLER: The steel in the spring will drop--the elasticity will drop and the strength will drop. The spring takes a permanent set so it won't come back to where its initial setting was.

MR. POLLARD: We have had a very definite reduction annealed in these springs. These relief valves, almost invariably the springs are stressed quite high, so that you can keep your crack to full flow down. It will probably affect it in that respect.

MR. BUMB: Another thing I've noticed is that the aluminum bodies have a different rate of expansion th... the steel, which also would put it off at the high temperature.

MR. CHATTLER: The aluminum body has a different rate of expansion than the spring.

MR. BUMB: I Know of one valve that we had where they run at 250 degrees F. It dropped off--I don't know what the value was--but it was about three or four hundred pounds, and you could calculate back and take into account the difference of expansion from the aluminum body to the spring; and I think we allowed about two percent reduction in loss of spring force, and we came out just about right on the nose; that you can predict the flow.

MR. CHATTLER: Does this make much difference in your cracking?

MR. BUMB: It was flowing at, I think--as I remember it--about 300 lbs., just at 250 degrees F.

MR. CHATTLER: That's a good point to watch. I guess we should start qualifying units at 275 degrees F.

The next item is actuating cylinders. The Navy has a contract with Bendix Pacific Division for 3000 psi 3" bore, 1" rod, 18" stroke 400 degrees F cylinders. In all of our developments, incidentally, we did not specify any sealing devices. As Mr. Maguire informed his pump people, we feel that in the end somebody might dream up something very juicy so that we could get away from all the "O" ring problems that we have.

The packing manufacturers have been running to us, asking us for data instead of the people who are developing cylinders and other components for high temperature. I hope some of them will start thinking about new types of sealing devices.

MR. MAYHEW: Are we planning on using any titanium in the cylinder?

MR CHATTLER: We didn't specify materials or seals. We didn't specify anything. We just said, "We want an item that will operate at 400 degrees F, tested in accordance with our cylinder specs."

It just so happens that Mr. Mettee has informed me that Bendix is planning on using titanium for this actuating cylinder, so we will get some information on that.

On our actuating cylinders, what basic problems might we have, other than the dynamic seal?

MR. MIDDLETON: Static seal.

MR. CHATTLER: You can use this metal "O" ring for static seal.

MR. KELLER: One problem we have noticed, Leo, is that we cannot use flex hose coming into the actuator at these temperatures. We don't have any flex hose; and if we don't have room--and only too often we don't have room--we get coils in the tubing leading into the actuator, particularly when we have a servo system in which to reduce or increase the damping. We wish to keep the servo valve as close to the actuator as possible. We have a considerable problem of both the oil and the tubing expanding as the temperature rises, and putting a side load on the actuator, actually putting this thing in bending.

We ran into what looked like it was going to give us a lot of trouble in terms of side-loading on actuators and producing boiling, and burning the actuator out that way.

MR. CHATTLER: You mean between the piston and the cylinder?

MR. KELLER: Yes.

We are going to some unusual expedients to get away from that. These are all, it so happens, on surface control actuators. We have relatively short strokes, but we are flange-mounting the body of the acutator to the structure, instead of tying it into a pin joint or bearing joint. We are just bolting the body of the actuator right onto the structure and having a short and very heavy foot coming out and then having another link between the end of the actuator, the rod end, and the surface; and that way, by having a short, stubby column which is firmly tied onto the structure, we hope to be able to take up these sideloads due to thermo-expansion without putting any bending on the actuator itself. Any bending that will come will be taken out in the structure, rather than in the actuator.

MR.CHATTLER: Mr. Keller says we should also worry about the bearing between the cylinder and the piston. That might get us into some galling problems. I imagine at 275 degrees F we probably won't have to worry about that. At some higher temperature we would get into trouble possibly in the 400 degrees F system.

Aside from that, there is the dynamic seal, that we probably will be in good shape on at 275 degrees F, but which will undoubtedly require some work at a higher temperature.

MR. BREMER: Has anyone done any work on metal seals? Is it Simmons or Oleard type?

MR. STRAUS: Work has been done with the Skinner type seal and the inconel is about 5000, somewhere in that neighborhood; and they pack them up, four to a pack.

They have a metallic adaptor, female and a male, somewhat similar to the AN-6228 and 29, I believe.

MR. BREMER: Do you not have a spring pick-up?

MR. STRAUS: No; and the results are very erratic. Both parts are not good.

We have the metal to work, however; we don't know whether the Teflon itself is dissimilar or the metal. There are two Teflon prefit packings backed up with the metal, prefit packings that will work at 3000 cycles, but at lower pressure, say 400 or 300, it works very badly.

MR. CHATTLER: Any other discussion on actuating cylinders?

MR. MIDDLETON: You have to worry about the clearances between the barrel and the piston.

MR. CHATTLER: Correct.

Were your tests on Teflon, Frank, applicable to 275 degrees F, also, or was that above your temperature?

MR. STRAUS: This was at room temperature.

MR. CHATTLER: You said you had some problems extruding Teflon?

MR. STRAUS: That was 300 degrees F. There was an error somewhere that more or less tied down this clearance job. It's on page 4, paragraph 1,b. It says: "Diametric clearances do not exceed .005." Now, the tests we've run so far, it would only apply to -33 over, I believe. That .005, we couldn't tie that down to all the other sizes. In other words, in the smaller rings it might be tighter; in larger rings it might be extended.

MR. CHATTLER: <u>The next item is filters</u>. WADC has a contract with Cuno Filter Corporation for 6 gpm 3000 psi 600 degrees F filter. What kind of filter is that, Bob?

MR. GREEN: That filter will be stainless steel; will have a stainless steel sinter element.

MR. CHATTLER: It's a stainless steel sinter element. I believe we had some interesting discussion on the present filters.

Does anyone else want to discuss degree of filtration at higher temperatures? In other words, when we go up in temperature, do we have to go up in degree filtration?

MR. KELLER: I think it is not a function of temperature, but a function of the type of service you have. We have some sintered bronze filters that we had made up to 10 micron specification, and I freely admit we have no way of checking whether or not we are getting 10 microns filtration from them. We are using these in services with servo valves. We have our own servo valve, Midwest Geophysical valves, and we are not having any trouble when we use that. At any temperature range we can operate the valve, which includes everything up to 400 degrees F.

I don't think we have a problem in functional temperature there.

MR. CHATTLER: What is the finest filtration?

MR. KELLER: Ten microns.

MR. CHATTLER: Douglas has a unit that they want two microns for.

Does anyone else have units that require higher degrees of filtration?

MR. MARTIN: There are some indications, I believe, in the literature that could be dug out, that in sinter-type filters, as you approach extremely small dimensional clearance requirements--for instance, at two-micron filtration--that service-life can become very short, due to their inability to hold very large quantities of contaminants.

Another possible--not failure--of this type of filter, but a thing that must be guarded against, is the difficulty of cleaning the elements. In other words, in many cases, the impacted small particles of dirt in sinter-type filters are almost impossible to clean by rigid chemical means, by hydrofluoric acid or some means, so they have to be discarded. We had some test work that indicates this, in regard to the very dirty types of oil. It could conceivably be a problem.

I mention it only as something to guard against.

MR. FORSYTHE: We have had some experience along that line with sintered materials, and in talking to the various filter people, we find that when you clean these you never get them finely clean. Each time you clean them, you get a finer degree of filtration, but you still have part of your dirt remaining from the old build-up; and, as you said, due to your lack of area in your sintered material, you get more convolutions of the paper in more area, and therefore you have better filter capacity and lower build-up.

MR. MARTIN: I think we have to adopt a new psychology. We have to adopt the psychology of throwing away more expensive elements--although, heaven knows, the paper elements aren't very expensive.

MR. POLLARD: It just costs you more to filter, that's all.

I believe G.E. has done some work in connection with this for autopilot components. In discussing this with them a month or so ago, we talked of staging a filter having a ten-micron filter followed by a two-micron filter, so as to reduce the amount of contaminants that the two-micron filter had to take out, and prolong its life thereby.

MR. CHATTLER: Incidentally, while we are on the subject of filters, I'd like to deviate for one moment. We have a proposal on the present installation drawing for the filters to decrease the space for removing the bowl. You all know, in the installation drawing we have a certain clearance that we require so we can remove the bowls. I have rejected that request because in several cases where we had the allowable limit, but the quarters were so tight that we could remove the bowl--and break the filter.

Now, Mr. Forsythe showed me several of the screens that are involved. In one screen you put the filter element in the bowl and then install the bowl and screw it up. Thereby the element is supposed to engage the upper part. Of course, when you are removing the bowl--this you cannot do any longer. Then your element is stuck up there and when you take it off there is a possibility of breaking it.

Shall we keep the same dimensions?

. . . There was general agreement . . .

MR. GREEN: Speaking of bowls, in this Cuno filter that we are buying, the bowl will be attached by bolts, rather than screwed ring. I think that will be an advantage in replacing a laboratory filter, because we don't know what kind of a seal we'll be using, and it may be some kind of metal seal where we will have to tighten the bolts very tight. That wouldn't be very good where you screwed the bowl on.

MR. FIELD: There is just one thing that worries me about most of these sintered metal filters that I've seen. They have very little area, and in my definition, I use the filter to take out dirt, so it has to have some area. If I don't have dirt to take out, I don't use a filter; but the ones I have seen, I am very much afraid, if I put them on a vibration test I would need other equipment to pick up the pieces of filter that came out.

MR. KLEVEN: Purolator has claimed to us that they have a non-metallic, high temperature filter which we have not been able to get any more information on. I wonder if anybody has heard of that?

MR. GREEN: We have heard of it, but we haven't received any of the filters yet.

MR. CHATTLER: That's right. We've had information from Purolator that they

EDITOR'S NOTE: Present Navy tests indicate that sintered metal filters are only 20% efficient compared to 95% of present paper filters.

do have a high temperature element they have been workin with. I don't know if it is some sort--I guess it is, some non-metallic element.

MR. SANFILIPPO: They have a non-metallic element, but they indicate that the price is going to be about ten times as high. It will give the same efficiency.

In regard to that Air Force development, however, I would like to indicate that they are going to provide comparable area of filtration to the present AN filter element. It is not going to be just that one conical surface. It is going to be convolute, or some kind of a vertical or horizontal section.

MR. FIELD: That part I like, but will it stand the shake?

MR. SANFILIPPO: That will have to come out in test. We will have to specify tests for that.

MR. BLAND, CHANCE VOUGHT: You need not only a high temperature filter element, but you need a filter element that can stand a little more pressure gradient across the element. For that reason, we would prefer a metal element, to high temperature Purolator.

MR. SHARP: In my experience, we'll have to prove the metal elements, because they won't take any bending.

MR. CHATTLER: To sum up on the filters, then, at 275 degrees F we may be all right with the present filter elements, but at 400 degrees F--we will have to investigate some other types of material.

MR. GREEN: I don't know whether we are all right at 275 degrees F. We had some trouble with elements, that is, with the glue in the element coming out, at high temperature. I don't know just what the temperature is where they fail.

MR. FORSYTHE: Purolator has notified us that the element is good for 275 degrees F, the bonding is good at 275 degrees F. We haven't tested that yet, but they have notified us to that effect.

MR. BREMER: We found that we had six to eight hours, at which time there was a break in the bond. So 275 degrees F is really getting quite close.

MR. CHATTLER: The next item is accumulators. The Navy has an order with Bendix Pacific Division for a cylindrical accumulator. I believe in that accumulator our problem is going to be, again, the seal, or the sealing means between the air and the oil side. The other problem we have in the 275 degrees F MIL-O-5606 system is: Are we going to blow up the accumulator with the oil in the air side. Talking about spontaneous combustion problems in the cylindrical accumulator--that is, oil getting into the air side--does it make any difference at 275 degrees F or 100 degrees F?

MR. MARTIN: Definitely.

MR. CHATTLER: Now you are going into a pressure area, don't forget.

MR. MARTIN: I think there is much literature to indicate--the Shell data will support that--that the higher the temperature of the fluid to begin with, the lower the temperature at which you can get spontaneous ignition, or with the more ease you can achieve this compression.

MR. BREMER: What if you use nitrogen?

MR. SHARP: Is that common practice in the service?

MR. CHATTLER: No, it is not common practice in the service.

MR. MARTIN: We have a dry set for use on our accumulators, dry nitrogen. We were running some production tests several weeks ago, using 2000 psi air and releasing it suddenly in an accumulator to charge the system. We were getting explosions.

MR. CHATTLER: We had one incident on a McDonnell airplane. They have a hydraulic motor application, and they wanted to use air for emergency operation .

Vickers said they would not guarantee the unit above 400 psi air pressure, because of the dieseling problem, although they had no tests. McDonnell has run about twenty or thirty shots with 3000 psi air, nothing happened.

MR. MARTIN: You can go a year and nothing will happen, and then (indication that there will be an explosion).

We have been running these tests for about a year and a half and never had any dieselization. All of a sudden, one week, we started getting bing-bing-bing, one right after the other; and I think now, running the production tests using nitrogen, we have gotten away from the problem; also trying to get all the oil out of the system that they can.

MR. SANFILIPPO: We ran many tests in that when we wanted to see how much leakage we could tolerate in the piston-type accumulator. We found out that with our standard air valve it is not possible to charge with such velocity as to cause spontaneous combustion. However, with the new valve, that is a question, there. If we eliminate the baffle provided by the present valve in the new valve, we may inject that possibility of causing spontaneous combustion. It always exists.

We put various amounts of liquid on the air side, and then for our test we use an open valve, a solenoid actuated air valve; in other words, the air piling in there as fast as possible, and we didn't get any appreciable combustion unless we had--well, I forget what the amount was--but it was maybe a cupful of oil in there.

MR. PAGLIARINI: We removed the air core and let the air in slowly, regardless of the pressure, but if you allow that charge of air to hit that puddle of oil inside that accumulator--we recorded temperatures up to 800 degrees F in an instant.

MR. MARTIN: All of these things point out that the important thing, the principle of the thing, is if the rate of rise is very high, you get a high rate of compression before you get explosion. If you get a high temperature liquid to begin with, you can tolerate an even less rate of rise, and it is one of those things that we have been trying for a year and a half now to get a reproducible method of checking with these things, because we have been working with an industrial problem along those lines where they are getting it quite regularly at plant air pressures of around 280 psi only.

They have a problem wherein high temperature gas is injected into this chamber because the oil on the walls--or this line, I should say--and the velocity of that incoming gas, plus the 280 psi pressure already in the line, plus the temperature of the incoming gas is enough so that they liberate about 60 feet of pipeline; and they are pumping natural gas at around 800 degrees F, and it just makes it very skiddy. We're looking for a non-inflammable fluid to handle it.

MR. MIDDLETON: It seems to me that the problem could be quite easily solved by just going to inert gas.

MR. CHATTLER: Right.

MR. MARTIN: This has been known for years, now; but how many years have we been going on finding and charging light gas oils with 2000 psi of air, just sitting back and hoping?

MR. MIDDLETON: I say, myself, take your regular pump to do it with. That is because we are normally working with temperatures which are low enough so that we haven't considered the problem.

MR. MARTIN: There is one more good reference on this, Leo, at least with some down-to-earth data in it. I believe you will recall it, the Walter Kidde report on various lubricants which showed the effect of greatest release and the type and configuration of the volume in which the air was released.

MR. CHATTLER: This reminds me of something else. We are now checking all of the schematics in all the airplanes to locate emergency air bottles that do not have check valves between the bottle and the control valve. We have just gone into one group of airplanes that has about half a dozen bottles in it, and we have been finding quantities of oil from one-tenth full to full in many airplanes.

So if you will, I would like you all to check over your systems and try to make plans for installing these check valves. This is another place where we may encounter this dieseling problem, aside from not having air for emergency operation.

To sum up on the cylindrical accumulator, we apparently, in the 275 degrees F system, should require that we use an inert gas, rather than air.

MR. FIELD: I just wanted to point out one thing that happened a number of years ago, where we used an inert gas to pre-charge an accumulator. It was perfectly safe with the air, so far as we could find out at the time, but some bright boy one night got the bottles shifted and charged them all with oxygen, and that can happen if you are depending on an inert gas. Some fool can use something that isn't.

MR. CHATTLER: The next item is hose. We had some discussion at the SAE meeting on that.

Wright Field has agreed to start running tests starting at 300 degrees F and going up, with the peak impulses that are presently required. At one point in our discussions we were talking about lowering the peak pressure for impulse testing, so that we can get some consistency in the life of our hose, and thereby only consider the temperature variable. Right now you would be considering the hose variable, as such, plus your temperature variable. However, in speaking to the Weatherhead Company they feel that they have enough test experience with the higher peak pressures, that is required peak pressure, so that they can get a good indication by maintaining this pressure and increasing the temperature.

This is something we have to do a lot of work on.

MR. STRAUS: I broke it up into two parts, the first part speaking of peak pressures. We took some -12 hose, which isn't the best hose to begin with, and we ran six of the samples at 150% peak, and recorded all the impulse-rate failures. Incidentally, they were all below a hundred thousand. Then we ran at 135% peak, going on the theory that lower peak pressures increased impulse-life. In one case, one out of the six, went a hundred thousand, but some of the others failed below limits that the 150% peak had gone to, which puts us back in the oil study, that there isn't enough data at our institute to tell us what peak pressures you can live with.

Another thing I should mention; that I think a lot of system peaks are getting a little above 4500. In fact, I think some of them have been electronically checked.

Along the line of high temperatures, I think that with the present design of compression-type fittings, especially on 3000 lb. hose, there is a terrific amount of compression between the hose insert and the liner; and bringing it down further, it is a known fact now that hose assemblies that have been stored for a long period of time --there is a certain amount of rubber deterioration under that compression area, and the first pressure of the hose assembly is--say, there are two hose assemblies from the same piece of hose in 1945. One is first tested at 10,000 plus. Three or four years later the first test on the other hose assembly will probably be about 7,000.

Now, to go to high temperatures, as any rubber man will tell you, higher temperatures will degenerate the rubber further, plus the fact that you already have a high compression area with a certain amount of deterioration, I don't think personally that we are even going to make 275 degrees F. We did age some hose about a week ago at 275 degrees F and tried to run it through and it blew the fittings right off. The hose itself leaked very badly. So I think we have a real problem on hose.

One possible solution is to raise our low temperature requirement. I don't know if it can be done, but it seems that it has to be done. For one thing, the tube of the hose runs about 85 durometer hardness, if I'm not mistaken. It's pretty hard, and it's pretty tough right now, even with 160 limit, 200, and what-have-you, to make the hose consistently pass about 165.

I think that covers the rubber and wire-type hose. Our metal hose contracts --the results haven't been too promising, but I think you are familiar with most of the metal hose construction; it's the convoluted stainless steel tube, and the end fitting is either brazed or cemented on. Usually we have fatigue failure on the bottom of the convolute. They did report one hose that went over a hundred thousand

cycles, but it came out that they did not impulse it. It was about six inches long, and the thickness of the convolute was .018, which is getting into the realm of tubing so the contract is still going on and we hope to get something on it. It's not too encouraging.

It may be well to try to work on the principle of coiled tubing or swivel joints if possible, to maintain alignment.

MR. MIDDLETON: Has anybody done any work with this Resistoflex hose that has a compound liner, metal oxide?

MR. BUMB: Yes.

MR. MIDDLETON: Did it work?

MR. BUMB: Not high enough pressure.

MR. CHATTLER: That brings us, then, to the possible substitutes for hose, one of which is of course the coiled tubing. I thought probably it would be in order for us to start establishing some general practices on coiled tubing. There have been several companies: Grumman, Martin--I believe--that have used coiled tubing very successfully, and we have a large number of installations of it, and off hand I don't believe I recall any failures.

MR. KELLER: Do you know, Leo, of any place where they have made any analysis of how many coils you need to take so much flexing?

MR. CHATTLER: I was going to bring that up. I think Douglas, El Segundo, has some design processes on it, and also Grumman; and I thought we might obtain that information.

Of course, we may have it at the Bureau already. It would be hard to find; and set up some design requirements for coiled tubing. Is that right, John?

MR. BURNS: We have some rule-of-thumb criteria.

MR. KELLER: That's what I'm afraid of.

MR. BURNS: As a result of combined analyses and tests that were conducted five or eight years ago, I guess, before we got too far in AD production; and we have, as Leo implied, extensive service application of coiled tubes, to show that if your excursion or angular deflection of your cylinder is 10 to 15 degrees, it's a very logical application for a coiled tube.

We are in the range of between two and four coils, usually, and the diameter of those coils, quarter-inch stainless steel material, is approximately two inches--two and a half inches diameter of loop.

MR.KLEVEN: We have been doing some design study with that, to bring our sizes up around a half inch, clearance for half-inch. Due to the size, we have no room for coiling, so we are making single, large U-loops out of it.

One thing we find is that this requirement of 10% stress increase is hard to meet, and we don't think that it is realistic and right, because this is stress in the longitudinal direction. So we feel that 15% is more likely; 16-1/2% can be analyzed, and indicates the same stress level as to tension in that same piece of tubing.

Another thing that enters into that is to arrange the fittings so that there will be no contortion on the fittings to tend to loosen them. The worse problem that we foresee is that due to fairly small displacements at the end of the tube, where it is secured, it will be very difficult to control the initial stress on installations that are not cycling up. The installation may actually bend the tube, and therefore it is apt to yield a point when it is operating. The fatigue life willbbe short.

MR. CHATTLER: Have you any installation report on that?

MR. BURNS: We have a number of decreased motion versus number of coils controlled, yes; but I don't have the data with me.

MR. CHATTLER: Al?

MR. WEISSKOPF: Since the advent of the 10% restriction, we have not tried to use the coiled tubing.

MR. CHATTLER: El Segundo always has--for the last six or eight years that I know of--worked very hard to keep hose out of their airplanes. They made very extensive studies in their airplanes at one time for replacing the pump pressure and suction lines with coiled tubing. They didn't have too much success, but I always felt they probably dropped it a little prematurely. It may be a workable solution. What was the final number of coils that you tried?

MR. BURNS: Eight or nine. We went from that to trying to build in a swivel connection, which didn't take into account all the degrees of motion that we can expect.

MR. CHATTLER: This was in a piston engine, was it not?

MR. BURNS: That's right. AD engine.

MR. CHATTLER: I was wondering if in a jet engine installation you may not be able to use coil tubing.

MR. MURPHY: In a jet engine it will become more critical, on account of high frequency.

MR. BURNS: The vibration was the other concern, yes.

MR. MURPHY: For our application, Leo, we don't pay too much attention to stress. We believe in testing every installation.

MR. CHATTLER: That's really what it means. If you can get a better wording for it, I am agreeable to changing it. I did calculate the stress at one time and tried to consider all stresses involved and to be on the safe side came up with the present requirement in MIL-H-5440. So you can be on the safe side by getting ridiculous, sometimes.

MR. DETWEILLER: About ten years ago we ran quite a few tests on universal swing joints, which was a combination swing joint and ball joint, and tried to replace hoses on power plants. We had more troubles with the packing in that than we had with the hoses, which were developed a little bit later.

On that same airplane, however, we did use coiled tubing on some of the actuating cylinders on the Constitution Airplane 3000 lb. system.

MR. CHATTLER: I remember those P2V's with the swivel joints. What a headache. That can get you into trouble, I know, we replaced them all with hose again.

This may be the solution, then; some form of swivel joints or the coil tubing or a combination, to replace the hose. Meanwhile, we will continue to investigage hose.

MR. GREEN: We have been very much interested in this coiled tubing idea, and felt that we don't know enough about it. We are planning to initiate a contract to have this studied, in order to obtain design criteria which can be generally used.

MR. CHATTLER: As far as I am concerned, we must go ahead and study this some more. I think Douglas has such fabulous service experience on these tubings that they can say: "Insofar as this is concerned, it should be all right." However, they don't have any high temperature experience.

MR. BURNS: Not with 275 degrees F.

MR. CHATTLER: At 400 degrees F you might have some trouble.

MR. GREEN: This study we visualize to be a study of what is available and what work needs to be done. Then if necessary we would proceed to conduct tests on any additional work that would need to be done to arrive at complete design criteria.

MR. CHATTLER: I think that is very much in order.

MR. MIDDLETON: It seems to me that business of finding something that will work in pump pressure and suction lines will be something that should be gone into. That seems to be the most critical application of all, because you can design around your cylinder application a lot more easily than you can around the suction line problem. That is probably one of the hottest places in an airplane.

MR. STRAUS: One of the hose companies came in with a sample, and they are going to send some in for test at low pressure; and you can use it as a suction line. They indicate they can run it at 350 degrees F top and -40 degrees F low. We are going to test it.

MR. MARTIN: How much time did they get?

We have run a number of pump tests on various fluids including 5606 at ov 240 hours. I wondered what sort of timing you were talking about?

MR. CHATTLER: What kind of peak pressures were you running?

MR. MARTIN: Those test, were pretty much non-pulsating pressures. I don't mean they are not pulsating; I mean they are pulsating to the extent that they are getting the pump pulse, but not the same type of pulse that you get in a hose test where you are pulsing between zero and three thousand. It is true of 4500 peak.

DR. MORETON: That's right. The pump doesn't get that on an airplane.

MR. MARTIN: There may be applications in aircraft where you don't need that sort of thing, but I think our experience so far has brought that out. We are trying to get a hose that simply passes the MIL-Specification test, and as a matter of fact, you go beyond that. We go beyond the MIL-Specification test again and again, and our hoses aren't the world's best.

DR. MORETON: I was just trying to get an idea of whether this was a freak, or what.

MR. CHATTLER: The margin of safety we have now--at least to me, it seems obvious, should be the same at higher temperatures. The degree of failures we are having now certainly would be accented if we went up to higher temperatures.

MR. STRAUS: Along that line, we have test data--and I think North American ran them, if I am not mistaken they ran AN-6292 hoses at 200 degrees F, impulsed 100,000 cycles or pretty close to it, 300 degrees F satisfactorily. However, the outer cover did tend to flake off. I think the point that should be brought to mind is the time temperature to be considered. In other words, this test, as I understand it, was run continuously for two days, or weeks, or whatever it takes; but in an airplane, you will have the high temperatures in there, and then it will be sitting on the ground. You may not fly for another week, and then you go up again and subject it to high temperatures, and over a prolonged period of time--six months, year or whatever it takes--eventually that rubber under that compression, that fitting, is going to weaken and you are either going to get a leak or a blowoff. I think that could happen even though it is 250 degrees F, over a long enough period of time.

Are there any other comments on hose, fittings and tubings?

MR. BREMER: We had several pieces of hose in high temperature test, and we found that on sectioning the hoses the internal liner was badly cracked. The hoses didn't actually leak or spray, but they did seep, prior to our taking them off and sectioning them. I have a feeling that possibly these hoses you have been running, if they were sectioned, you would find them cut.

MR. MURPHY: We have been running hose tests for so long, day in, day out, month after month, on hoses. There is no good hose, as far as I know, at present, at 160 degrees F or 300 degrees F.

MR. CHATTLER: <u>Next we will cover the system requirements</u>. The only item I have under system design requirements for a 275 degrees F system is the airless-type system. Now the only thing that I don't know is, where should we start that requirement; at 200 degrees F? Most of the new aircraft are coming through with the airless-type systems, but there are some of the higher-speed airplanes, the new airplanes, that

still have the oil reservoir with the air pressure on top of the reservoir. Maybe we should say that at 200 degrees F and above it would be very desirable to go to the airless-type system; and for the record we will say that the services will examine systems, and where the temperatures are above 200 degrees F, we will ask that the air-frame manufacturers seriously look into using an airless-type reservoir.

Are there any other design conditions?

MR. BUMB: Is there anybody doing anything--I suppose somebody is doing something on lubricants? That's a very vital factor in this picture.

MR. CHATTLER: You mean lubricating fluids?

MR. BUMB: I mean, lubricating the ends of swivel joints, and that sort of thing.

MR. CHATTLER: Lubricants or fluids? Yes, we spoke about that at our last meeting, and--do we have anything in here on it?

We were talking about lubricants for bending tubings, and actually I guess we had reference to lubricants insofar as fabrication was concerned, so that the materials we use be compatible with the fluids we were developing. I don't believe we had any reference to lubricants for something, as a swivel joint.

MR. BUMB: The end fittings of our hydraulic cylinder in atmosphere of--well, maybe not 275 degrees F, I'm thinking of a higher temperature as we get into a higher temperature, you have a lubrication problem of keeping lubricants in the end of a hydraulic cylinder.

MR. CHATTLER: On the rod?

MR. BUMB: On the rod--on the swivel joint. I am thinking of the ball-joint at the end of the rod.

MR. CHATTLER: Oh, the fittings.

MR. BUMB: The special grease.

MR. CHATTLER: There are high temperature lubricants, Dick.

MR. MARTIN: 3278

MR. BUMB: We haven't found anything, unless we haven't found the right thing.

MR. MARTIN: 275 degrees F for sure.

MR. MAYHEW: The point I wanted to bring out on--actually, I am going back to the cylinders--nobody mentioned anything about temperature over 400 degrees F. What are we going to do over 400 degrees F? Has anybody looked into asbestos-type wipers?

MR. STRAUS: I checked on that about two months ago with the Materials Lab, about the high temperature limitations of felt, and such, and they thought that felt was in the same category as leather back-up rings; in other words, an animal fibre, and there is no continuous lubrication to felt.

There is one thing, when the fluid is driven out, you just have the dry fibre, and it will char just like leather.

However, there was one representative from the American Felt Company, who said he would go back and see if they could get any kind of data, but so far we haven't received it; but they are working on it.

It is very probable that leather back-ups are in the same category as felt.

MR. KELVEN: As I mentioned before, we checked up on felt, but only up to 350 degrees F. In doing it, though, we had recommended to us--I think it was orlon of of the synthetic fibres--as being capable of going much higher. We found that the

Types 5 and 7 were satisfactory to 350 degrees F. We didn't go any further with it.

MR. MARTIN: Running high temperature tests we found that the felt apparently didn't do much good. We got failure just as readily with felt in there as with felt removed. That was run with raw temperature of 150 degrees F. Now, when you get up into higher temperatures, it doesn't seem to me that the felt is earning its keep, because the felt isn't actually doing the job of lubrication that you think it is doing. At least, it seemed that way to us.

MR. CHATTLER: You think it is drying out.

Of course, some people designed the cylinders so that you gave them a shot of juice every time you actuate.

MR. MARTIN: We put little grooves in there that are supposed to keep the felt lubricated, but it remains static for quite a period of time and the rod gets hot, then the felt dries out, anyhow; and neither the felt nor the leather did any good, in that case.

MR. KELLER: We're not using felt. We haven't had any trouble. We have a total of fifty hours of operation. We're not using any wiper at all.

MR. MARTIN: In George's place, he is using a relatively low volatile material.

MR. CHATTLER: Are you saying we won't have this trouble with OS-45?

MR. MARTIN: I'm not saying we won't have it with OS-45 or any other low-volatility material of any nature, but it is minimized; and you run into trouble with 265 degrees F level because you are getting an evaporated condition. We can jump up, certainly, another hundred degrees, and maybe a hundred and fifty, before you reach the equivalent of operative condition with the synthetics. That is the only real reason they ever started the industry in the first place, based on their low volatility. This is a ramification of the old ANG grease problem.

MR. CHATTLER: That about winds up our discussions. I also wanted to ask you whether you felt we should have another meeting like this a year from today, so we can tie down the 400 degrees F fluid. I've had enough indication from most of you people here that you would like to see another meeting about a year, so we will plan on having that; let's say somewhere around the first part of next year.

MR. BURNS: I have one general question, and that is in regard to all items that are now, say, an AN part number, and you issue QPL's equivalent to obtain those for the temperature range of 275 degrees F. Is there reidentification procedure on all those pieces?

MR. CHATTLER: Yes, reidentification will be required. I have that on my notes here. We are going to start to re-develop our specifications to bring them up to 275 degrees F. We also have a program set up to start testing standard parts to see if we can qualify them for 275 degreesF.

MR. ROTHGERY: I might mention, I would like to say for the benefit of the meeting, this developmental program which the services have, if there were some way that you could make some of these airplane manufacturers know just what type of fluids, or where these fluids are being developed, or their availability, it would certainly help.

MR. CHATTLER: All you do is make sure you get hold of a copy of the minutes, and you will have it all in there. We will also send you progress reports.

There is a test report on the MLO-8200 fluid that will be issued.

MR. MURPHY: I would like to ask what the intent of the 275 degrees F requirement is, as far as specifications. If you have an airplar that normally operates in the 160 degrees F range, is it going to be affected at all by this? Will it stay there, or do I have to design it for 275 degrees F?

MR. CHATTLER: Negative. Any specs that we bring out that cover the 275 degrees F range, these specifications will in no way affect or cancel the existing specifications for 160 degrees F.

MR. MURPHY: I was thinking more of 5440.

MR. CHATTLER: In 5440, we may start creeping in some requiremnts for higher temperatures.

MR. MURPHY: Will it require that the airplanes be satisfactory within that temperature range?

MR. CHATTLER: Right now it says that it shall be satisfactory within the temperature range that we designed the system for. This will carry us for some time.

MR. MURPHY: I was just wondering if we would have to qualify the parts, like at the present time, if we now have 120 degrees F level system we have to qualify to 160 degrees F.

MR. CHATTLER: I'm afraid we won't be able to do that at the present time.

MR. MURPHY: I'm not saying we won't be able to. We just don't want to.

MR. CHATTLER: It would be ridiculous for us to go out now and say: "Okay, if you can't meet 160 degrees F, you have to meet 275 degrees F." You know we can't say that, because it has to be on a build-up process. We, however, can't start qualifying components at every temperature in the book, so what we will do is probably start running tests for 275 degrees F on our present components. The contractor parts should be tested at the temperature that you have set for the upper limit of your airplanes.

In closing, I wish to thank all of you for coming. I want you to express mine, the USAF and Navy's appreciation to your companies for allowing you to come and participate in this meeting.

In addition, I hope that each one of you feel that this has been a worthwhile conference. I certainly believe that it has been.

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APPENDIX 1

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1. INTRODUCTION

1.1 The operational temperature of the hydraulic system in present production aircraft has exceeded the old accepted maximum of 160 F, and has approached 250 F. Satisfactory operation has been maintained with relatively no changes in design or materials. Qualitative investigation has shown that the operational temperatures cannot be allowed to increase further without losing satisfactory performance and suitable life from present designs and materials. To control the temperature is a major thermodynamics problem with increased speeds resulting in higher skin temperatures. To alter design and change some materials, appears to be necessary and requires considerable investigation to allow higher system operating temperatures.

1.2 Considerable effort has already been expended by numerous organizations in the investigation of materials for use in a high temperature hydraulic system. To review past accomplishments and adopt a program for the development of a high temperature hydraulic system appears necessary.

2. PURPOSE

2.1 To assemble all available information on performance of hydraulic systems and components at temperatures above 250 F.

2.2 To determine the direction and amount of added knowledge needed at this time.

3. SUMMARY

3.1 The results of tests conducted in the development of a high temperature hydraulic system are summarized in Tables I through VI.

3.2 The work to be accomplished in furthering the development of a high temperature hydraulic system is shown on Table VII.

4. REQUIREMENTS OF A HIGH TEMPERATURE HYDRAULIC SYSTEM

4.1 The general requirements of a high temperature hydraulic system are presently 50 hr of satisfactory operation at 400 F and satisfactory operation at temperatures from -65 F to 400 F. Obviously these would be very near the minimum requirements for pilot controlled non-expendable aircraft.

4.2 The fluid should have a maximum kinematic viscosity of approximately 2500 centistokes at -65 F. This is about the

FORM 18-G-1 REV. 2-47

maximum viscosity allowable for practical operation of a hydraulic pump. A minimum kinematic viscosity of 1.0 centistokes at 400 F would probably give satisfactory performance of the pump based on pump tests conducted in Ref. 2, 5, 6, 7, 9, and 10. A maximum vapor pressure of 3 mm of Hg. at 400 F would assist pump performance by suppressing cavitation and would prevent excessive loss of fluid due to vaporization. The fluid should have satisfactory hydrolytic stability and thermal stability, it should have satisfactory oxidation and corrosion characteristics with inhibitors, a minimum flash point of 400 F, a pour point below -65 F, and satisfactory lubricity for steel on steel wear.

4.3 Obviously the remainder of the system must be compatible with the fluid or vise-versa. Also each unit must perform its function satisfactorily over the required temperature range for the time specified.

5. PRESENT STATUS OF HIGH TEMPERATURE HYDRAULIC SYSTEM

5.1 Fluid

5.1.1 The progress made in the development of a high temperature hydraulic fluid has been summarized on Tables I, II, and III. The OS-45-1 Silicate-ester fluid is presently considered the best of those available and is being used in all tests above 250 F. Limited operational use of this fluid has been made at temperatures of 400 F with no unfavorable comments. A small system utilizing this fluid has been operated at -65 F with performance equal or superior to that of the same system operated with MIL-O-5606 fluid.

5.2 Pumps

5.2.1 The tests that have been conducted with pumps above an operating fluid temperature of 250 F are summarized in Table IV. The principal difficulties that have been encountered are: (1) piston-bore clearance problems, (2) packing difficulties, (3) lack of lubricity of fluid in the pump-fluid combination, and (4) thermal differentials resulting in internal stresses and distortion causing binding of moving elements.

5.2.2 Considerable inertia of pump manufacturers to development of a high temperature pump has been experienced. This reluctance has been principally due to the lack of information on the fluid situation. Presently all of the major aircraft hydraulic pump manufacturers are attempting to produce pumps

capable of high temperature operation with silicate-ester fluids.

5.3 Systems

5.3.1 A summary of tests conducted on system components is given on Tables V and VI. The principal difficulties encountered above 250 F involve packings. Present activity is centered primarily on the packing problem in evaluating new compounds for compatibility with OS-45-1 fluid. Preliminary screening for swell characteristics and general compatibility with temperature are presently being conducted by the Material and Process Group of the Engineering Research Section. Suitable rubber compounds will be further tested in the Engineering Research Laboratory for friction and wear characteristics under dynamic conditions at various temperatures.

5.3.2 Presently a small system is being operated with OS-45-1 fluid at an operating temperature of 300 F for the purpose of evaluating a current model of a variable volume pump for endurance at 300 F with a silicate-ester fluid.

6. DIRECTION OF FUTURE EFFORT

6.1 Work to be Accomplished - The work to be accomplished in the development of a high temperature hydraulic system is outlined in Table VII. The effort to be expended industry wide in developing a high temperature hydraulic system is probably commensurate with that which has been expended in developing hydraulic systems to this date. Inasmuch as considerable effort will be expended by numerous other organizations the effort to be expended by North American Aviation should be that which is required to meet its needs. Since the operational temperature of the hydraulic system will progress approximately 50 F per new model aircraft, suitable systems should be developed at approximately the same rate.

6.1.1 Fluid - A constant evaluation of OS-45-1 fluid should be made as it is used in various tests. Also new fluids should be evaluated in the search for a fluid capable of higher operating temperatures with better performance of the hydraulic system with greater economy if possible.

6.1.2 Pumps - Pumps will have to be evaluated to meet the requirements of the hydraulic system throughout the expected operational temperature range.

6.1.3 System Components - The various system components will have to be evaluated to meet the requirements of the hydraulic system and to provide the required operational control of the hydraulic system throughout the expected operational temperature range.

6.1.3.1 To provide a means of being able to analyze a system component for possible satisfactory operation a considerable amount of effort should be directed to the physical properties of typical units. Basic problems such as the spring rate of various metallic springs affect the performance of many units in a hydraulic system. Also clearances are a physical feature of practically every mechanical device and should be thoroughly investigated. Considerable difficulty has been experienced with cylinder rod-end bearings. Suitable lubricants for bearings must be developed and evaluated for high temperature use. A suitable filter must be adapted for aircraft use. Flexible joints must be evaluated.

6.1.3.2 An aircraft operating at high speed for a period of one or two hours will probably never reach a stabilized temperature condition; therefore suitable performance must be achieved under transient temperature conditions. With a large temperature range of variation the heat transfer properties of a unit may be the deciding factor in acceptable performance, and the methods of testing units should include determination of these heat transfer properties, as well as operation under changing environmental conditions.

6.2 Reporting - In order to provide current information on the status of hydraulic systems, it is proposed to issue a progress report as an addendum to this report every three months. This progress report will summarize all known activity in the development of a high temperature hydraulic system and provide a list of references on the subject for more detailed information. It will be distributed to all interested groups.

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FORM 18-G-1 REV. 5-47

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8. TABLES

TABLE I

GENERAL FLUID TYPES*

Fluid Type	Advantages	Disadvantages
Organo-Phosphorous Compounds	1. Reduced flammability 2. Good lubricity	1. Requires additives to obtain desirable viscosity - temperature relationship 2. Requires additives to impart oxidation and hydrolytic stability 3. Questionable thermal stability for extended use in presence of metal catalysts
Dicarboxylic Acid esters	1. High flash point 2. Low pour point 3. Good thermal stability 4. Non-corrosive with proper inhibitors	1. Requires additives to obtain desirable viscosity - temperature relationship
Carbonates	1. Viscosity - volatility and viscosity - temperature characteristics superior to petroleum base stocks	1. Poor thermal stability
Borates	1. Viscosity - temperature characteristics superior to petroleum base stocks	1. Very poor hydrolytic stability
Polyglycols	1. Good lubricating qualities 2. Viscosity - volatility and viscosity - temperature characteristics superior to petroleum base stocks	1. Questionable thermal stability 2. Requires thickening agents for use as high temperature hydraulic fluid
Silicates	1. Excellent Viscosity - volatility viscosity - temperature characteristics 2. Good shear stability	1. Inhibitors required for oxidation and hydrolytic stability 2. Questionable high temperature stability and flash point
Polysiloxanes	1. Excellent viscosity - temperature and viscosity - volatility characteristics 2. Good thermal stability and resistance to shear and oxidation 3. High flash point, low pour point	1. Poor lubricity
Halogen organic compounds	1. Excellent resistance to chemical attack, oxidation, hydrolysis, and heat	1. Very poor viscosity - volatility and viscosity - temperature characteristics 2. Cholorine containing organics are toxic, exhibit poor stability, and have limited high temperature stability

*Taken from Ref. 1

TABLE I[illegible]

SUMMARY OF FLUIDS

Fluid	Manufacturer	Type	Reason for Rejection	Ref.
Plexol 201	Rohm and Haas Co.	di (2-ethylhexyl) sebecate	No compatible seals	9
Plexol 202	Rohm and Haas Co.	di (sec, amyl) sebecate	Cracked at 450 F	9
DLB-50 BX	Union Carbide and Chemical Co.	Polyalkylene glycol	Excessive vapor pressure	9
Plexol A-26	Union Carbide and Chemical Co.	di (2-ethylhexyl) adipate	No compatible seals	9
DC-510	Dow Corning Corp.	Silicone	Poor lubricity	9
XF-60	Dow Corning Corp.	Silicone	Poor lubricity	9
Kel F No. 1	Kellog Co.	Fluorocarbon	Excessive vapor pressure	9
RPM "A"	Std. Oil of Calif.	Hexachlorabutadiene	Excessive vapor pressure	9
Skydrol	Monsanto Chemical	Phosphate-ester	Excessive vapor pressure	9
Orsil BF-1-S	Oronite Chem. Co.	Silicate-ester	Low viscosity	9
Fluorolube Std.	Hooker Electrochemical Co.	Chlorofluorocarbon	Poor viscosity index	9
MLO-5277*	Calif. Research Corp.	Silicate-ester	Not rejected	9
MLO-6938	Calif. Research Corp.	Silicate-ester	Lubricity, sludging, corrosive	6
OS-45	Monsanto Chemical	Silicate-ester	Not rejected	9,5,4
PRL-3161	Rohm and Haas Co.	di-ester	Lubricity	9
PRL-3039	Rohm and Haas Co.	di-ester	Excess vapor pressure, lubricity	9,5,4
MIL-O-5606	---	Petroleum base	Poor lubricity, flash point 245 F	4,5

*Formula 52742

TABLE III

PHYSICAL CHARACTERISTICS OF TYPICAL HYDRAULIC FLUIDS

Item	OS-45-1	MLO-5277*	MLO-6938	MIL-O-5606
1. Viscosity				
-65 F	2000 ctks	2800 ctks	2700 ctks	1900 ctks
0	90 ctks	200 ctks	200 ctks	100 ctks
100	8.50 ctks	32 ctks	28 ctks	14.2 ctks
400	0.95 ctks	3.2 ctks	--	--
600	0.56 ctks	1.8 ctks	--	--
2. Flash point	405 F	350 F	335 F	200 F
3. Fire Point	460 F	395 F	375 F	245 F
4. A.I.T.	696 F	693 F	693 F	300+ F
5. Sp. Gr. at 60 F	0.896	0.90	0.90>	0.865
6. Vapor pressure				
400 F	0.09 psi	0.05 psi	--	0.81 psi
500 F	0.78 psi	---	--	--
600 F	7.00 psi	---	--	--
7. Neutralization	0.12	0.05	0.04	0.17

*MLO-5277 is a predecessor of MLO-6938 and is identical to CAL. Research Corp. Formula 52742

TABLE IV

PUMP TESTS

Pump	Fluid	Time and Temp.	Remarks	Ref.
New York Air Brake Pump A-126 Type 67A050	MLO-5277	40 hr at 75-160 F then	Satisfactory	9
		1 hr at 250 F then	Satisfactory	
		1 hr at 350 F then	Satisfactory	
		1 hr at 400 F	Pistons scored, piston pads rounded, shaft seal leakage	
New York Air Brake Pump A-207 Type 67F050	OS-45	40 hr at 75-160 F then	Satisfactory	9
		1 hr at 350 F	Cylinder block stuck tight in aluminum housing, piston pads rounded severly.cylinder bores galled shaft seal leakage	
Vickers PF 24 3906-20-BCE-4 (3000 psi, 3750 rpm)	MIL-O-5606	22.2 hr at 300 F	Failed to maintain pressure	5
		22.2 hr at 300 F	Failed to maintain pressure	5
	PRL 3039	6.0 hr at 300 F	Failed to maintain pressure	5
		7.1 hr at 300 F	Rotating group failed	5
	OS-45	136.4 hr at 300 F	Failed to maintain pressure	5
		208.6 hr at 300 F	No failure	5
	MLO 6938	40.5 hr at 300 F	Failed to maintain pressure	6
		198.5 hr at 300 F	Rotating group failed	6
Vickers PF14-3911-25ZG (3000 psi, 3600 rpm)	MIL-O-5606	25.0 hr at 300 F	Considerable wear	3
	52742	19.6 hr at 300 F	Shaft seal failure	3
	52742	14.5 hr at 300 F	Shaft seal failure	3
New York Air Brake Model L-PC-89 No. A-101 (300 psi, 3750 rpm)	MIL-O-5606	0.5 hr at 80-265 F	Complete failure Pistons siezed	17
New York Air Brake Model 66WA300 (3500 rpm, 3000 psi)	Formula 53257 (MLO 6938)	25 hr at 160 F then	Satisfactory	2
		25 hr at 250 F then	Satisfactory	
		25 hr at 300 F then	Satisfactory	
		0 hr at 350 F	Pistons froze at 330 F	

TABLE V

TESTS OF SYSTEM COMPONENTS AND UNITS

Unit	Mfg.	Part No.	Fluid	Temp. F	Remarks	Ref.
Accumulator	NAA	157-58029	MIL-O-5606 OS-45 PRL 3039	300 300 300	O-rings unsatisfactory after 50 hr of testing with each fluid	10
Backup Rings	---	AN 6244 and AN 6246	MIL-O-5606	300	Charred, hardened, and disintegrated after 44 hr use	10,8
			MLO 5277	250	Carbonized after 1 hr use	9
		5R12 or Equivalent	MIL-O-5606	300	Slight feathering	10
			OS-45	300	Slight feathering	10
			PRL 3039	300	Slight feathering	10
			MLO 5277	300	Slight feathering	16
			OS-45	400	Extruded after 1 hr use	9
			MLO 5277	400	Extruded after 1 hr use	9
Cylinder, Actuating	---	---	MLO 5277	300	O-rings unsatisfactory	16
	---	---	MLO 5277	400	Packing failure	9
	NAA	157-58029	MIL-O-5606	300	O-rings unsatisfactory	10
			OS-45	300	O-rings unsatisfactory	10
			PRL 3039	300	O-rings unsatisfactory	10
Filter Elements	Purolator	AN 6235-2A	MIL-O-5606 MIL-O-5606 OS-45 PRL 3039	300 300 300 300	25 hr maximum use allowable, then charring and cracking	10,8 5 10,8 10,8
	Permanent Filter Corp.	Special	PRL 3039, OS-45 and MIL-O-5606	300	Good filtering, entirely satisfactory, suitable replacement for AN 6235	15
Fittings	---	AN 818	All shown in table	to 400	Excessive torquing required for satisfactory sealing	10,9, 16
Flow Regulators	Waterman	196-6-140	MIL-O-5606 OS-45 PRL 3039	300 300 300	Satisfactory operation of regulator but O-rings unsatisfactory	10
Hose	---	MIL-H-5511	MIL-O-5606	300	Surface cracking and failure	10,13
			MLO 5277	300	Failure	15
		MIL-H-5512	MIL-O-5606 OS-45 PRL 3039	300 300 300	Permanent set and surface cracking. Extreme resistance to flexure	10,13
		MIL-H-5512	MLO 5277	300	Permanent set and brittleness	16
O-ring	Linear	AN 6227 and AN 6230	MIL-O-5606	300	Permanent set, weakened	10
			OS-45	300	Permanent set, weakened, shrinkage	10
			PRL 3039	300	Permanent set, weakened, swelling	10
	Various	Special Compounds			None satisfactory for use with OS-45 fluid	7,8,10, 11,12,14,16
Pressure Switch	Meletron	15121523	MIL-O-5606 OS-45 PRL 3039	300 300 300	Satisfactory operation during 200 hr use - actuated approximately 50 times	10
Tubing	---	---	All listed	to 400	No difficulties reported	
Solenoid Valves	Adel	24700	MIL-O-5606	300	Solenoid failure after 44,000 cycles, 41 hr use, O-rings unsatisfactory, Excessive internal leakage	10
	Saval	25412	MIL-O-5606	300	Same as above	10
	Mar Vista	11070	PRL 3039 OS-45	300 300	O-rings unsatisfactory excessive internal leakage	10

TABLE VI

OPERATIONAL TEMPERATURE LIMITATIONS OF TYPICAL HYDRAULIC SYSTEM COMPONENTS AND UNITS

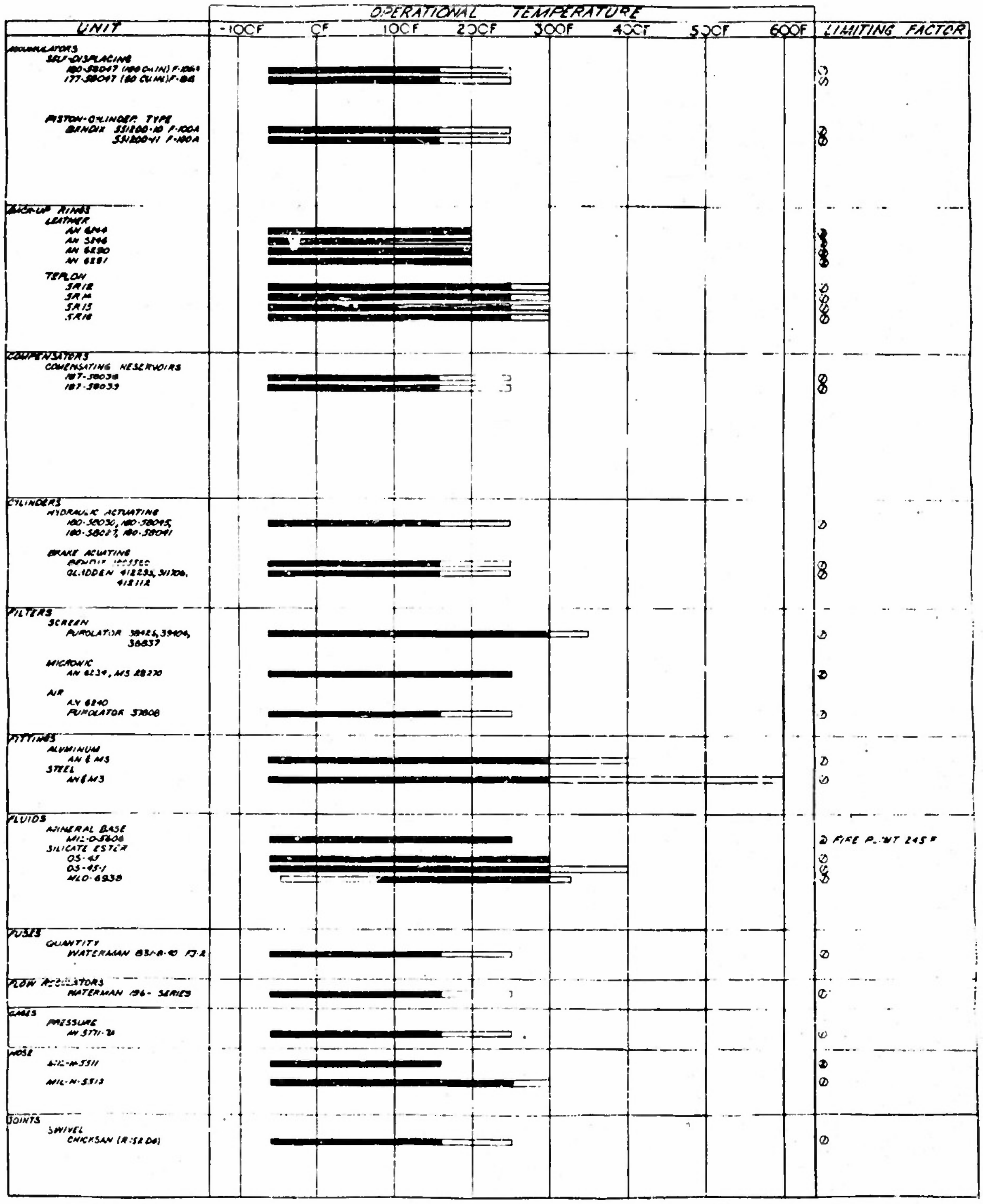

TABLE VI CON'T

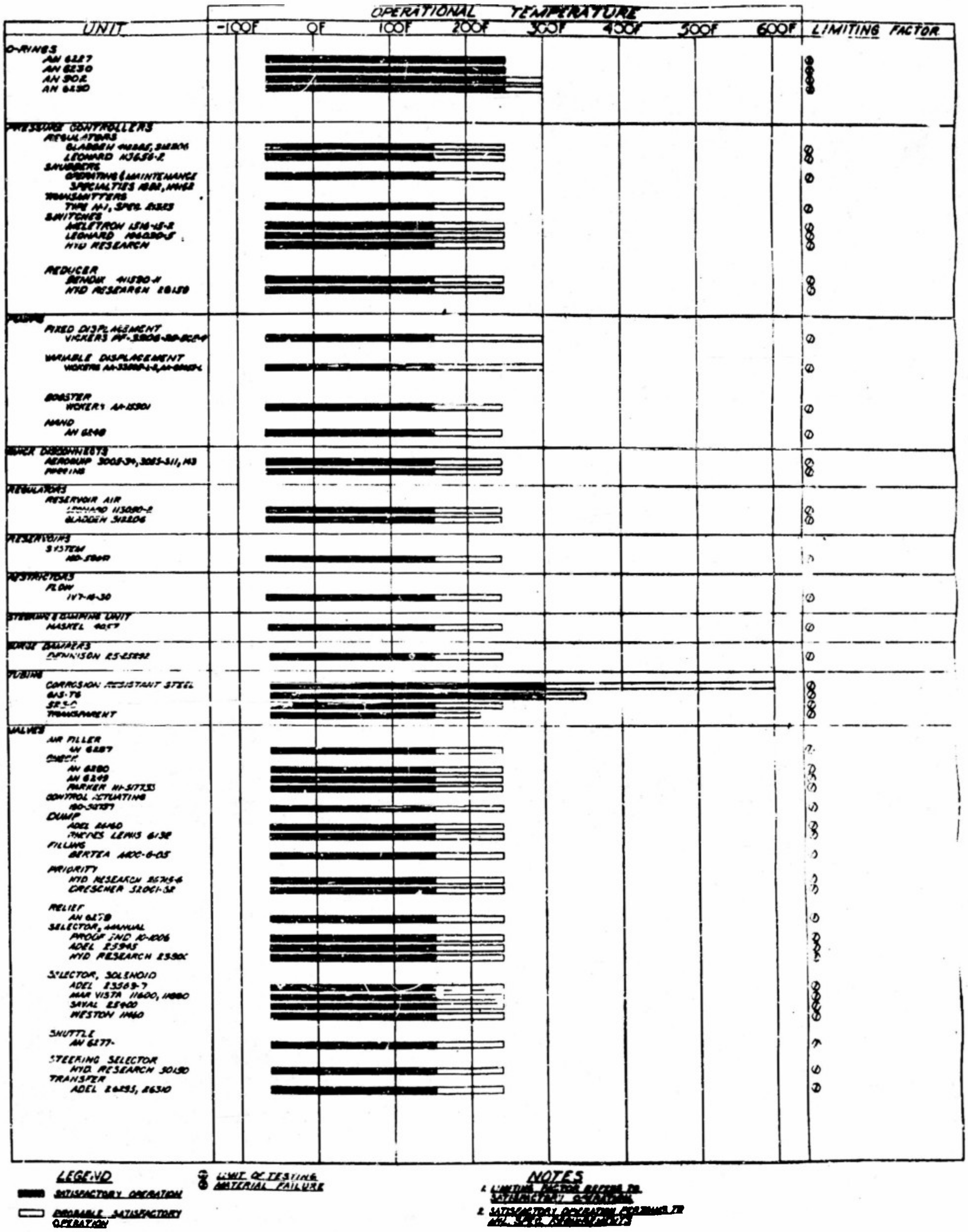

TABLE VII

WORK TO BE ACCOMPOLISHED IN DEVELOPMENT OF
A HIGH TEMPERATURE HYDRAULIC SYSTEM

Field	Work to be Accompolished
Fluid	1. Constant evaluation of OS-45-1 fluid when used in various tests. 2. Determination of fluid friction, compressibility factors, extension of design data to new fluids 3. Evaluation of other fluids in search for a fluid superior to OS-45-1 at 400 F 4. Evaluation of other fluids in search for a fluid suitable for 600 F operation
Pumps	1. Evaluation of pumps to satisfy requirements in 400 F range with OS-45-1 2. Evaluation of pumps for compatability with fluids superior to OS-45-1 3. Performance tests of acceptable pumps for response, pressure-flow characteristics, etc. in the 400 F range with accepted fluid 4. Evaluation of pumps with suitable fluids above 400 F
System Components Actuating Cylinders	1. Analysis of present actuating cylinder design with respect to strength - weight ratio between aluminum alloy and other materials. Effect of temperature differentials on clearance. 2. Performance analysis of above evaluation with burst and assembly tests 3. Performance of individual units for typical operation at high temperature and high differencial temperature between fluid and ambient
Filters	1. Evaluation of sintered metal filters
Hose	1. Impulse and flex tests of improved hose for 400 F operation with silicate-ester fluids 2. Impulse and flex tests of metallic flexible units
Joints	1. Evaluation of swivel joints at high temperature and satisfactory operation throughout temperature range
Packings	1. Evaluation of O-ring compounds for use below 400 F both static and dynamic seals 2. Evaluation of new type packing for hydraulic use for full temperature range 3. Evaluation of backup rings for use with O-rings
Tubing	1. Fatigue life of aluminum and steel tubing at high temperature
Valves	1. Analysis of clearances in typical valves at extreme temperatures and extreme differential temperatures between fluid and ambient
Springs	1. Analysis of spring rate as a function of temperature for various types of metallic springs
Bearings	1. Evaluation and search for bearings suitable for operation at high temperatures and satisfactory throughout temperature range
Lubricants	1. Evaluation and search for suitable lubricants for bearings at high temperatures and satisfactory throughout temperature range
System Tests	1. Operation of mock-up system at 300 F, 350 F, 400 F, 450 F, 500 F, 550 F, and 600 F when suitable materials for such a system become available

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APPENDIX 2

HOT TEST NO. 2 DATA SHEET

Note: The circled numbers correspond to the circled numbers on the Hot Test No. 2 temperature vs. time curve.

1 Conditions of Test Setup

A. New filter elements (AN 6235-4A) were installed in both pressure and return line filters.

B. The hydraulic fluid was the same as used in Hot Test No. 1.

C. The pump from Hot Test No. 1 was used.

D. No accumulator was used this test.

E. The test piston was installed using SK11-29346-5 teflon cap strips with silastic #7180 "O" rings (AN6230-1 size) as pressure members.

F. The rod gland seals were the SK11-29323 teflon channel lip type with silastic #7180 "O" rings (AN 6227-19 size) as pressure members.

2 The AN6227-33 "O" ring static seals at both cylinder heads started leaking at 1375 cycles. They were not replaced.

3 The 4 way solenoid operated cycling valve was replaced with an air operated 4 way valve.

4 The test was discontinued at 20,000 cycles when one of the rod gland seals was leaking badly. On disassembly the teflon lip was found to be badly abraded while the silastic #7180 "O" ring

had almost disintegrated. The rod seal on the other end though not so badly worn was leaking. A static pressure check of the piston seal showed 0 leakage.

Both filter elements (AN6235-4A) were failed with cracks at the inside radius of the convolutions.

			REVISED	DATE	
CALC					HOT TEST NO. 2 DATA SHEET
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APPD					
APPD					BOEING AIRPLANE COMPANY SEATTLE 14, WASHINGTON

PAGE 2

BAC 973 D-R3

TEMPERATURE vs. TIME
HOT TEST NO. 3

BOEING AIRPLANE COMPANY
SEATTLE 14, WASHINGTON

CALC	J.W. BILL		REVISED DATE
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APR			

PAGE OF 3

HOT TEST NO. 3 DATA SHEET

Note: The circled numbers on this sheet correspond to the circled numbers on the hot test No. 3 temperature vs. time curve.

1 Conditions of Test Setup

A. New filter elements (AN6235-4A) were installed in both pressure and return lines.

B. New hydraulic fluid was put in the reservoir after the system had been drained and flushed.

C. Used Model 67WF300 (N.Y.A.B.) pump was overhauled and installed on the setup.

D. The accumulator with standard AN 6227 "O" rings was pre-charged to 1500 PSI.

E. The test piston was installed using SK11-29346-5 teflon cap strips and silastic #7180 "O" rings (AN-6230-1 size) from Hot Test No. 2.

F. The rod gland seals were a special KEL-F coated silastic #7180 "O" ring (AN6227-19 size) with solid teflon back-up rings.

2 After 847 cycles, the special "O" rings in the rod gland failed and were replaced with standard AN6227-19 "O" rings. The KEL-F coating on the special rings had burst and allowed the silastic #7180 "O" ring to become abraded.

3 The AN6227-33 "O" ring static seals at both cylinder heads were leaking. They were not replaced.

(4) At 25,601 cycles a total of 50 1/2 hours of operation, the test was discontinued due to excessive leakage of the cyl. head "O" rings and increased leakage of the piston cap strip seals. The rod gland seals did not leak at this point. Both filter elements (AN 6235-4A) were failed with cracks at the inside radius of the convolutions.

			REVISED	DATE
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HOT TEST NO. 3 DATA SHEET

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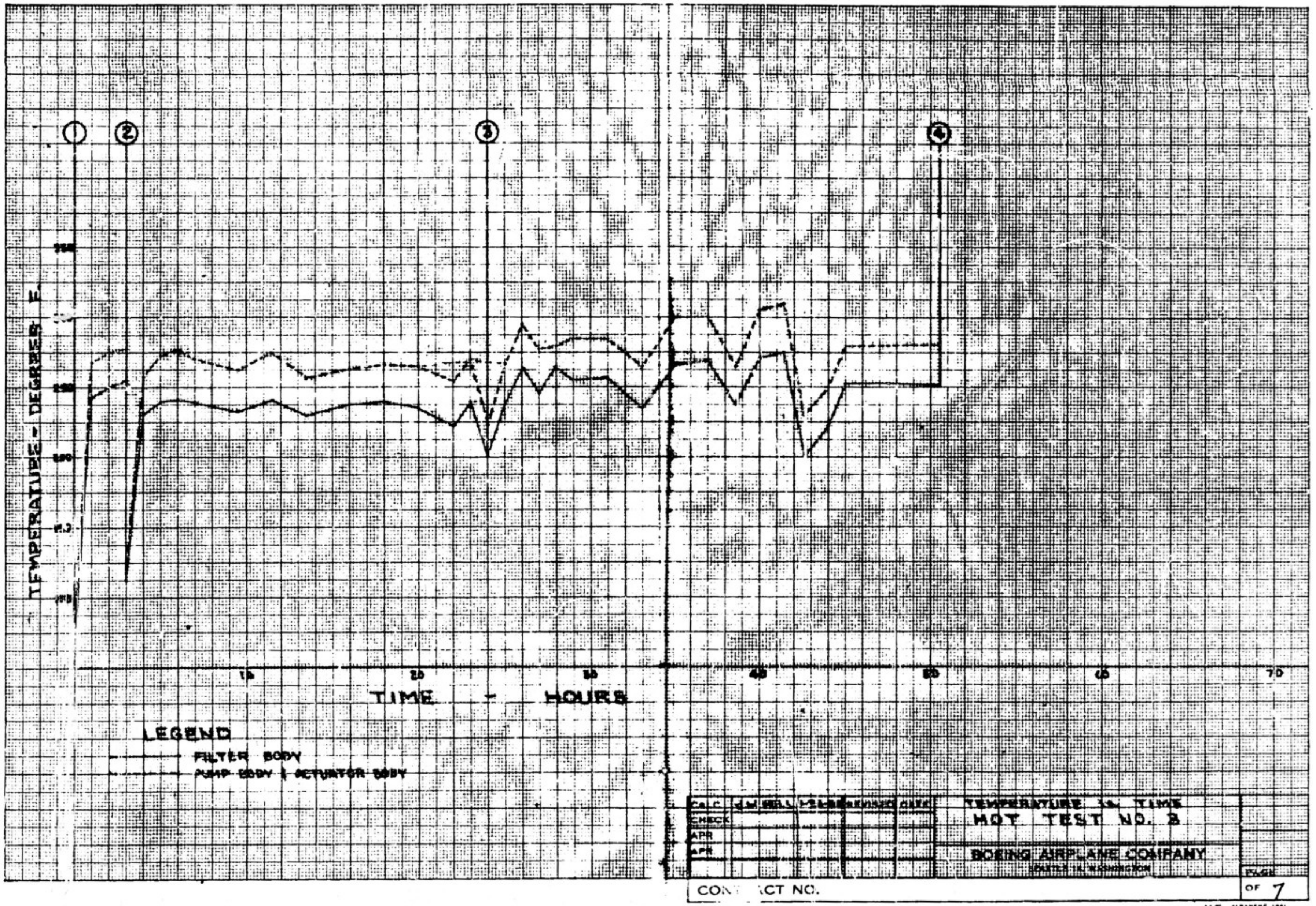
SEATTLE 14, WASHINGTON

BAC 973 D R3



1
2
3
4
TEMPERATURE - DEGREES F
10
20
30
40
50
60
70
TIME - HOURS
LEGEND
FILTER BODY
PUMP BODY & ACTUATOR BODY
CALC
CHECK
APR
APR
REVISED
DATE
TEMPERATURE VS. TIME
HOT TEST NO. 3
BOEING AIRPLANE COMPANY
CONTRACT NO.
PAGE
OF 7
K+E

HOT TEST NO. 4 DATA SHEET

Note: The circled numbers on this sheet correspond to the circled numbers on the hot test No. 4 temperature vs. time curve.

1 Conditions of Test Setup

A. New filter elements (AN6235-4A) were installed.

B. New hydraulic fluid was used after the system had been drained and flushed.

C. The pump from hot test No. 3 was used.

D. The accumulator piston was installed with an SK11-31616 teflon lip type seal using an AN6230-8 "O" ring as a pressure member.

E. The No. 1 actuator was installed with:

1. Piston seals - SK-29346-3 teflon cap strip AN6230-1 "O" ring pressure member
2. Rod gland seals - AN6227-19 "O" ring seal solid teflon backup ring

F. The No. 2 actuator was installed with:

1. Piston seals - SK11-29346-4 teflon cap strip AN6227-28 "O" ring pressure member
2. Rod gland seals - SK11-31615 teflon lip type seal AN6227-19 "O" ring pressure member

2 Shut Down for Pump Failure (total 58 1/2 hours)

A. Replaced pump with N.Y.A.B. 66WF300 newly overhauled and run-in pump. Former pump had pinhole leak in pressure port.

B. Both filter elements (AN6235-4A) had failed and were replaced. (total 8 hours)

C. The accumulator seal failed and was replaced with an SK11-teflon cap strip with an AN6227-36 "O" ring as a pressure member. (total 8 hours and 1,900 cycles)

D. New oil was put in the system.

3 Down for Night

4 Down for Weekend

5 Down for 1 hour - AN6227-33 HD. seal leaking and replace.

6 Down for Night

7 Down for 1 Hour - AN6227-33 HD. Seal Leaking

8 Down to Repair Leakage

A. No. 2 actuator removed - severe leakage past SK11-29346-4 cap strip some leakage (5 drops/min.) past SK11-31615 teflon lip type rod seal. (total 43 hours and 8,133 cycles)

B. Put in teflon (solid) bakcups with AN-6227-33 "O" rings at head seals.

C. The accumulator precharge which had dropped to 850 psi was raised to 1850 psi.

D. Installed No. 3 actuator with:

1. Piston seals - SK11-31593 teflon cap strip silastic #7180 "O" ring (AN6227-29 size) as pressure member

CALC		REVISED	DATE	HOT TEST NO. 4 DATA SHEET	
CHECK					
APPD					
APPD				BOEING AIRPLANE COMPANY SEATTLE 14, WASHINGTON	PAGE 10

BAC 973 D R3

2. Rod gland seals - AN6227-19 "O" ring seals solid teflon backup rings.

(9) Down for Severe Leakage

A. Removed No. 1 actuator - severe leakage past SK11-29346-3 teflon cap strip. Rod gland seal O.K. (total 47 hrs. and 9,172 cycles)

B. Replaced silastic #7180 pressure member in No. 3 piston seal with std. AN6227-29 "O" ring. (Total 4 hrs and 1,039 cycles)

C. Reinstalled No. 2 actuator with AN6277-29 "O" ring as pressure member in place of AN6227-28. All else the same.

(10) Down for Night

(11) Discontinued Test

A. SK11-29346-4 teflon seal not leaking but AN6227-29 "O" ring pressure member permanently deformed. (total 25 hrs. and 5,297 cycles)

B. SK11-21593 teflon seal abraded badly at thin section but not leaking. (total 29 hrs. and 6,764 cycles) AN6227-29 "O" ring pressure member badly deformed and abraded. (total 25 hrs. and 5,297 cycles)

C. SK11-31615 teflon lip type seal - deformed and torn at lip. (total 68 hrs. and 13,530 cycles)

D. AN6227-19 "O" ring seals with solid teflon backup rings failed at "O" ring. (total 29 hrs. and 6,754 cycles).

E. Both filter elements (AN6235-4A) failed on removal.

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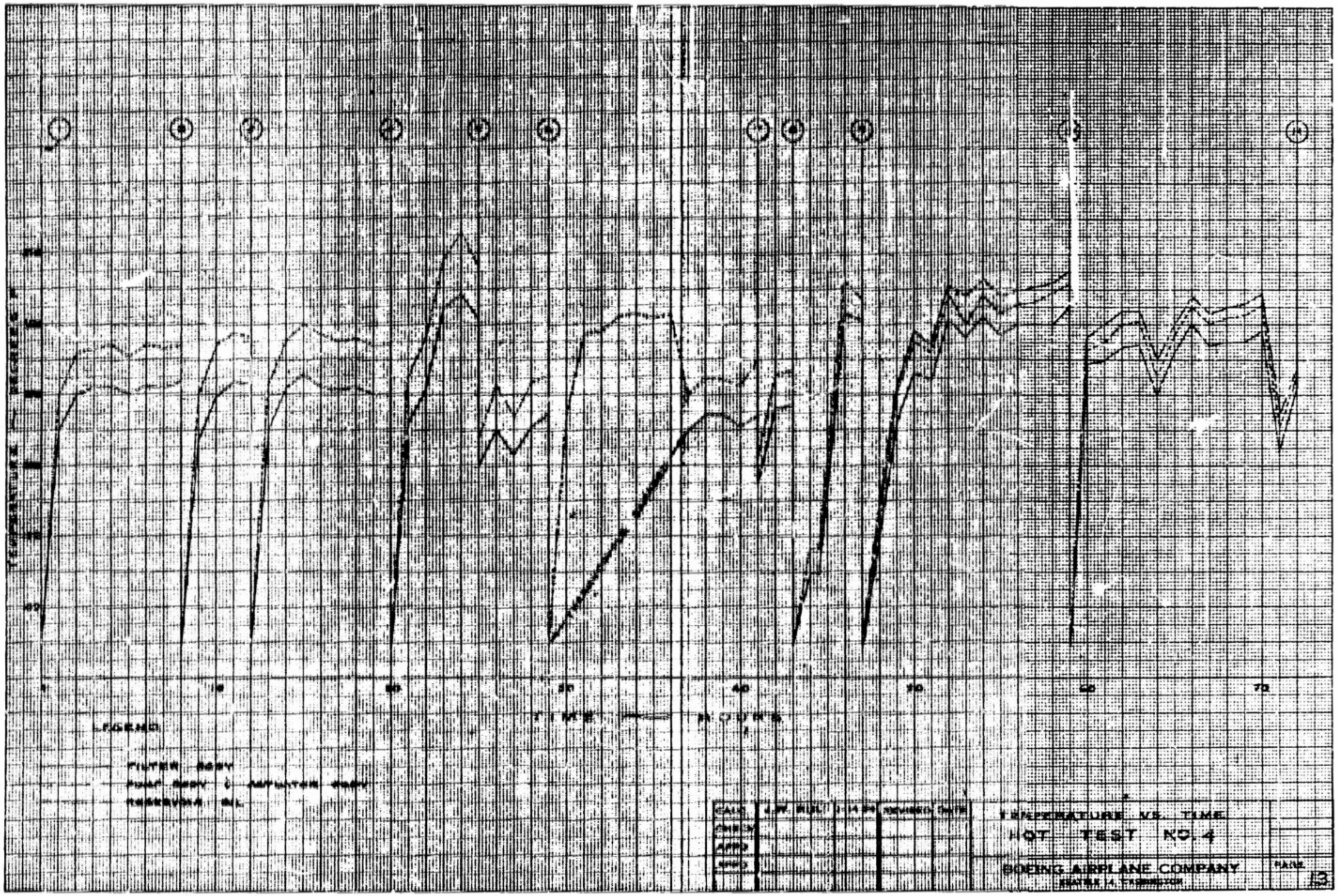
APPD					BOEING AIRPLANE COMPANY SEATTLE 14, WASHINGTON	PAGE 11


TIME — HOURS
0
10
20
30
40
50
60
70
LEGEND
FILTER BODY
TEMPERATURE VS. TIME
HOT TEST NO. 4
BOEING AIRPLANE COMPANY
SEATTLE 14, WASHINGTON
PAGE
13
K+E ALBANENE

HOT TEST NO. 5 DATA SHEET

Note: The circled numbers correspond to the circled numbers on the Hot Test No. 2 temperature vs. time curve.

1 Conditions of Test Setup

A. New filter elements (AN6235-4A) were installed in both pressure and return line filters.

B. The system was drained and flushed and new hydraulic fluid was installed.

C. The pump from Hot Test No.4 was used.

D. The accumulator ~~from Hot Test No. 4 was used.~~ WAS INSTALLED WITH SK11-32157 TEFLON CAP STRIP SEAL AND PRECHARGED TO 1500 PSI

E. The No. 1 actuator was installed with:

1. Piston seal - (2) SK11-31593 teflon cap strip
AN 6227-29 "O" ring pressure member
2. Rod gland seal - AN6227-19 "O" ring seal
solid teflon backup rings.

F. The No. 2 actuator was installed with

1. Piston seal - (2) SK11-29346-6 teflon cap strip
AN6227-29 "O" ring pressure member
2. Rod gland seal - AN6227-19 "O" ring seal solid teflon backup rings.

2 Cycling valve failed and replaced.

3 The No. 2 actuator was removed. SK11-29346-6 teflon cap strip seal leaking badly. Teflon member slightly extruded and AN6227-29 pressure

member badly deformed. (Total 26 hrs. and 4.500 cycles).

4 The pump body to head static seals failed and were replaced. The leather backup rings were badly charred. (Total 115 hrs.)

5 Replaced "O" ring seal at pump servo adjusting screw.

6 Down for leakage

A. Replaced AN6227-33 "O" ring static seals at test actuator heads. (Total 67 hrs. and 26,172 cycles).

B. Replaced both failed AN6235-4A filter elements. (Total 67 hrs.)

C. Removed failed pump (N.Y.A.B. 67WF300) with piston feet pounded out. (Total 131 hrs.)

D. Installed used N.Y.A.B. 67 VB300 pump.

E. Replaced AN6227-29 and AN6227-19 "O" rings in test seals.

7 Seal failed in pump by-pass cap - replaced.

8 Seal failed in pump by-pass cap - replaced.

9 Seal failed in pump by-pass cap - installed. Overhauled N.Y.A.B. 67WF300 pump.

10 AN6227-29 "O" ring failed in test seal. (Total 6 1/2 hrs.). Replaced failed "O" ring also put in new AN6227-19 "O" ring at rod gland seal. Soaked at 300°F for 7 days before resuming cycling.

HOT TEST NO. 5 DATA SHEET

Note: The circled numbers correspond to the circled numbers on the Hot Test No. 2 temperature vs. time curve.

1 Conditions of Test Setup

A. New filter elements (AN6235-4A) were installed in both pressure and return line filters.

B. The system was drained and flushed and new hydraulic fluid was installed.

C. The pump from Hot Test No. 4 was used.

D. The accumulator ~~from Hot Test No. 4 was used.~~ WAS INSTALLED WITH SK11-32157 TEFLON CAP STRIP SEAL AND PRECHARGED TO 1500 PSI

E. The No. 1 actuator was installed with:

1. Piston seal - (2) SK11-31593 teflon cap strip
   AN 6227-29 "O" ring pressure member
2. Rod gland seal - AN6227-19 "O" ring seal
   solid teflon backup rings.

F. The No. 2 actuator was installed with

1. Piston seal - (2) SK11-29346-6 teflon cap strip
   AN6227-29 "O" ring pressure member
2. Rod gland seal - AN6227-19 "O" ring seal solid teflon backup rings.

2 Cycling valve failed and replaced.

3 The No. 2 actuator was removed. SK11-29346-6 teflon cap strip seal leaking badly. Teflon member slightly extruded and AN6227-29 pressure

			REVISED	DATE	
CALC					HOT TEST NO. 5 DATA SHEET
CHECK					
APPD					
APPD					BOEING AIRPLANE COMPANY SEATTLE 14, WASHINGTON

BAC 973 D-R3

member badly deformed. (Total 26 hrs. and 4.500 cycles).

(4) The pump body to head static seals failed and were replaced. The leather backup rings were badly charred. (Total 115 hrs.)

(5) Replaced "O" ring seal at pump servo adjusting screw.

(6) Down for leakage

A. Replaced AN6227-33 "O" ring static seals at test actuator heads. (Total 67 hrs. and 26,172 cycles).

B. Replaced both failed AN6235-4A filter elements. (Total 67 hrs.)

C. Removed failed pump (N.Y.A.B. 67WF300) with piston feet pounded out. (Total 131 hrs.)

D. Installed used N.Y.A.B. 67 VB300 pump.

E. Replaced AN6227-29 and AN6227-19 "O" rings in test seals.

(7) Seal failed in pump by-pass cap - replaced.

(8) Seal failed in pump by-pass cap - replaced.

(9) Seal failed in pump by-pass cap - installed. Overhauled N.Y.A.B. 67WF300 pump.

(10) AN6227-29 "O" ring failed in test seal. (Total 6 1/2 hrs.). Replaced failed "O" ring also put in new AN6227-19 "O" ring at rod gland seal. Soaked at 300°F for 7 days before resuming cycling.

(11) Shut down test

A. SK11-31593 teflon cap strip seal badly abraded. (Total 78 hrs. and 34,422 cycles).

B. AN6227-19 and AN6227-29 "O" rings in test seals permanently deformed and abraded. (Total 4 1/2 hrs. and 1,825 cycles).

C. Accumulator seal O.K. but precharge down to 500 PSI.

D. Both AN6235-4A filter elements failed.

			REVISED	DATE		
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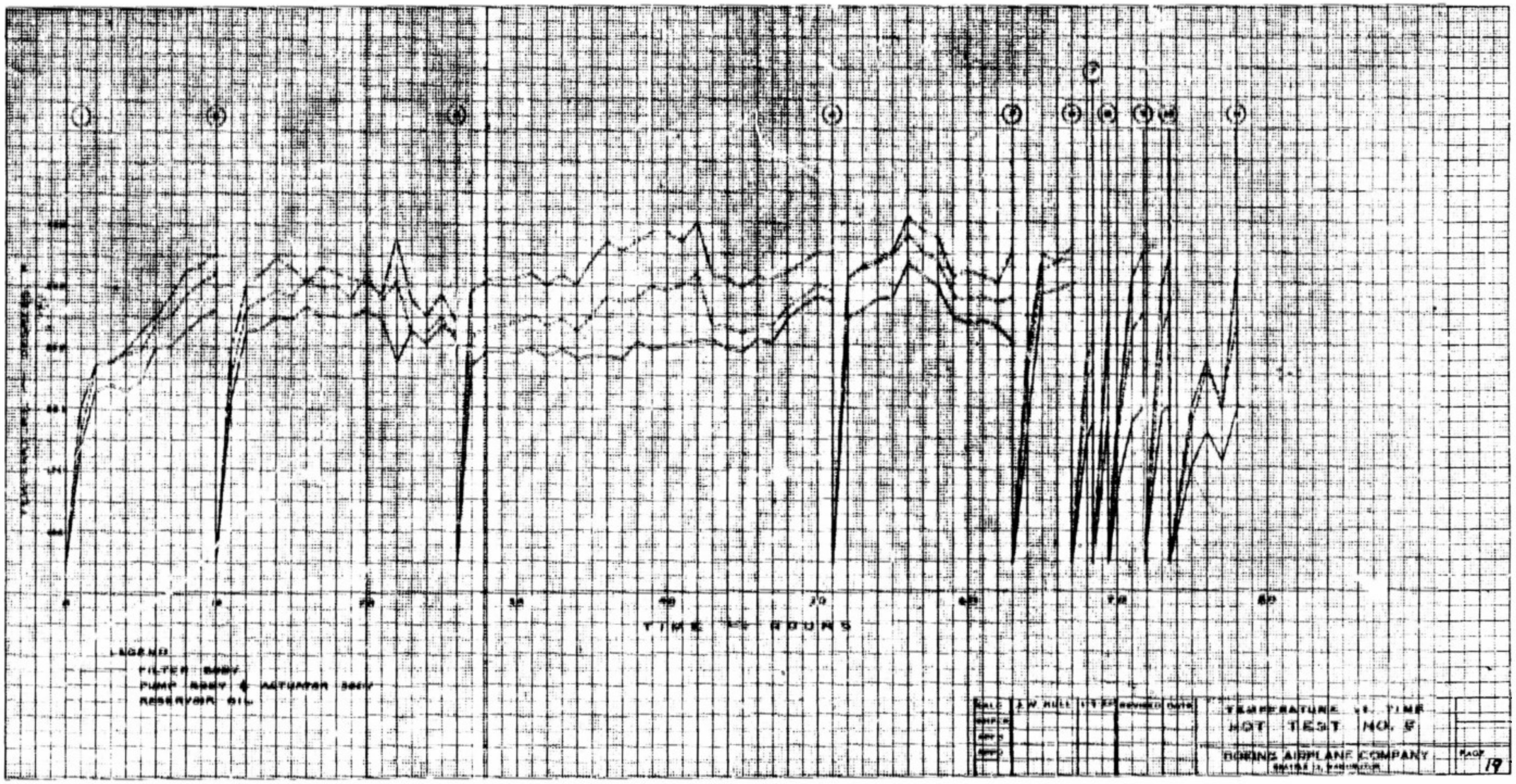
CHECK						
APPD						
APPD					BOEING AIRPLANE COMPANY SEATTLE 14, WASHINGTON	PAGE 17



TIME — HOURS
LEGEND
FILTER BODY
PUMP BODY & ACTUATOR BODY
RESERVOIR OIL
TEMPERATURE VS. TIME
HOT TEST NO. 5
BOEING AIRPLANE COMPANY
19

HOT TEST NO. 6 DATA SHEET

Note: The circled numbers on this sheet correspond to the circled numbers on the hot test No. 4 temperature vs. time curve.

1 Conditions of Test Setup

A. New filter elements (AN6235-4A) were installed in both pressure and return line filters.

B. After the system had been drained and flushed, new fluid was installed.

C. A new pump (N.Y.A.B. 66WA30C) was installed.

D. The accumulator from hot test No. 5 was precharged to 1500 psi.

E. The test actuator was assembled with SK11-31593 teflon cap strips with AN6227-29 "O" ring pressure members on the piston and AN6227-1? "O" rings with solid teflon backup rings in the rod glands.

2 Down for Night

3 Replaced AN6227-26 Static Seal "O" Rings between Piston & Rod.

4 Down for Night

5 Down for Night

6 Down for Night

7 Down for Inspection

A. Disassembled and examined pump. All O.K.

CALC			REVISED	DATE	HOT TEST NO. 6 DATA SHEET	
CHECK						
APPD						
APPD					BOEING AIRPLANE COMPANY SEATTLE 14 WASHINGTON	PAGE 21

BAC 973 D R3

B. Installed new AN6227-19 "O" rings and spiral teflon backups in rod glands. Old backups badly extruded. (Total 150 hours and 49,339 cycles).

(8) Replaced cycling valve - sleeve static "O" rings failed.

(9) Replaced cycling valve - added teflon spiral backups to valve sleeve static "O" ring seals.

(10) Discontinued Test

A. Test actuator head failed.

B. Both filter elements failed. (Total 57 hours).

C. SK11-31593 cap strip worn but not leaking. AN6227-29 pressure member deformed but not brittle. (Total 57 hours and 29,623 cycles).

D. AN6227-19 "O" ring seals and spiral teflon backup rings in good shape. (Total 20 hours and 10,295 cycles).

E. Accumulator precharge down to 950 psi. Accumulator seal SK11-31616 not abraded but the "O" ring was flat and brittle. (Total 207 hours).

F. N.Y.A.B. 66WA300 pump O.K. except for loss of pressure to 2650 psi.

CALC			REVISED	DATE	HOT TEST NO. 6 DATA SHEET	
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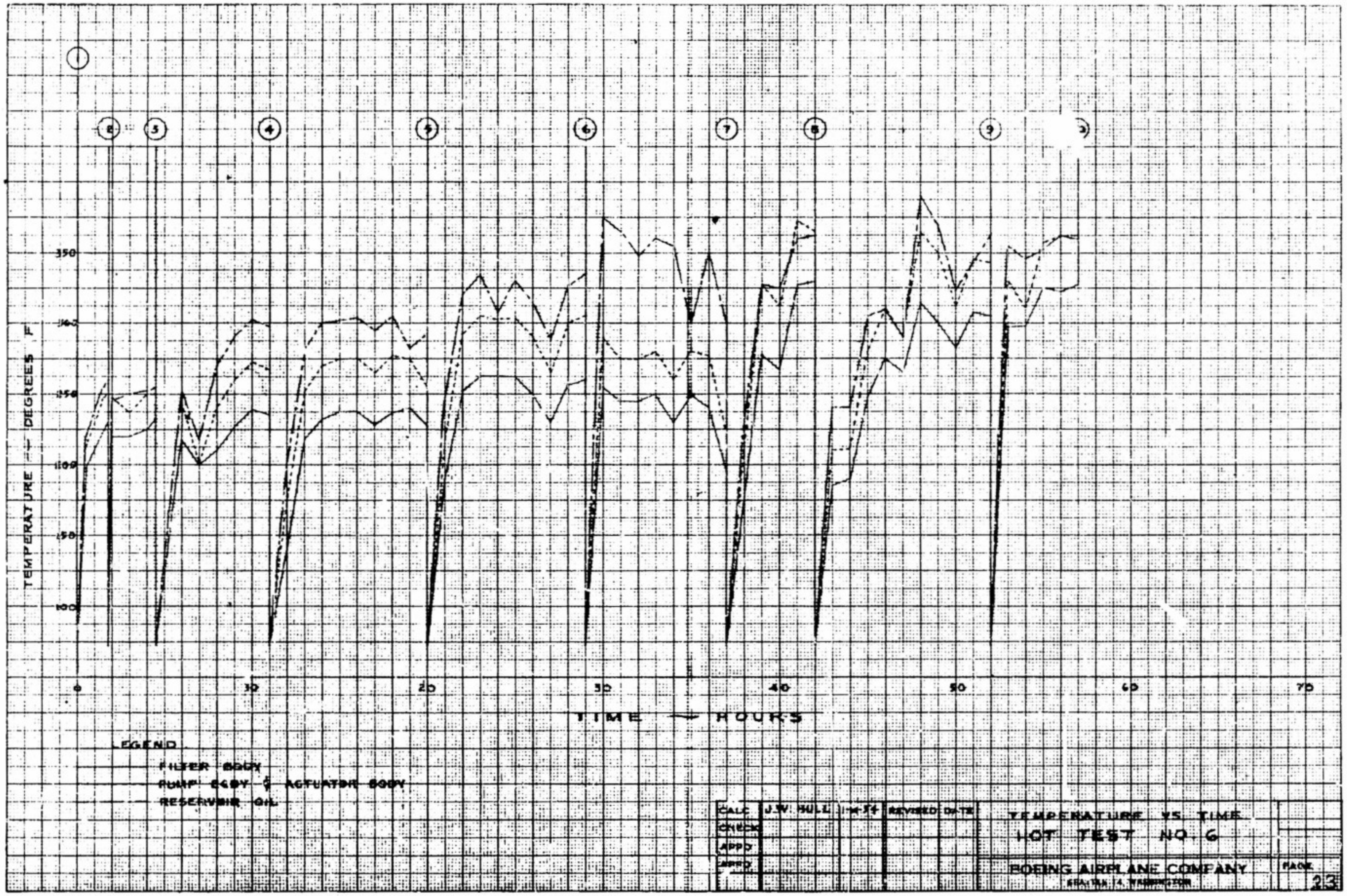
APPD						
APPD					BOEING AIRPLANE COMPANY SEATTLE 14, WASHINGTON	PAGE 22

BAC 973 D-R3


TEMPERATURE — DEGREES F
100
0
20
30
40
50
60
70
TIME — HOURS
LEGEND
FILTER BODY
PUMP BODY & ACTUATOR BODY
RESERVOIR OIL
CALC J.W. HULL
CHECK
APPD
APPD
REVISED DATE
TEMPERATURE VS TIME
HOT TEST NO. 6
BOEING AIRPLANE COMPANY
SEATTLE 14, WASHINGTON
PAGE 23

HOT TEST NO. 7 DATA SHEET

Note: The circled numbers on this sheet correspond to the circled numbers on the hot test No. 7 temperature vs. time curve.

1 Conditions of Test Setup

A. New filter elements (AN6235-4A) were installed in both pressure and return line filters.

B. After draining and flushing the system, new fluid was installed.

C. The pump from hot test No. 6 was used.

D. The accumulator was assembled using AN6227-33 "O" ring with special teflon backup rings on the piston and precharged to 1500 psi.

E. The test actuator was installed using:

1. Piston seals - AN6227-29 U.S. Gasket Co. "O" rings
   U. S. Gasket Co. spiral teflon backups

2. Rod gland seals - AN6227-19 U. S. Gasket Co. "O" rings
   U.S. Gasket Co. spiral teflon backups

2 Down to Repair Setup

3 Down for Night

4 Down for Night

5 Pump Body to Head "O" Ring Seal Failed - Replaced with Double "O" Ring. (Total 75 hrs.)

(6) Replaced U.S. Gasket Co. AN6227-29 and -19 with "Plastic and Rubber Products" "O" Rings of Same Size (Total 22 hrs. and 19,326 Cycles)

(7) Replaced 4 way Cycling Valve

(8) Down to Replace Broken Tube.

A. Accumulator Precharge down to 1150 psi, recharged to 1500 psi.

(9) Down for Night

(10) Down for Night

(11) Down to Replace Broken Line

A. Both AN6235 filters failed and replaced. (total 51 hrs)

B. New fluid in system.

C. AN6227-33 "O" ring in accumulator abraded, replaced. (total 51 hours)

D. AN6227-29 and -19 seals abraded, replaced (total 29 hrs and 35,600 cycles)

(12) N.Y.A.B. 66 WA300 Pump Seized. (Total 110 Hrs.) Replaced with Overhauled 67 WF300 pump.

(13) Down for Night

(14) Down for Night

(15) Down for Night

(16) Down for Failed Pump

A. Replaced cracked pump head

B. Replaced failed AN5235-4A filter elements. (Total 12 hrs.)

C. Accumulator precharge down to 950 psi. Recharged to 1500 psi.

17 Down for Night

18 Down for Night

19 Down for Night

20 Pump Case Failed All Around. Replaced with New Case.

21 Removed Pump and Ran in with a Mixture of Molybdenum-Disulphide and Oil.

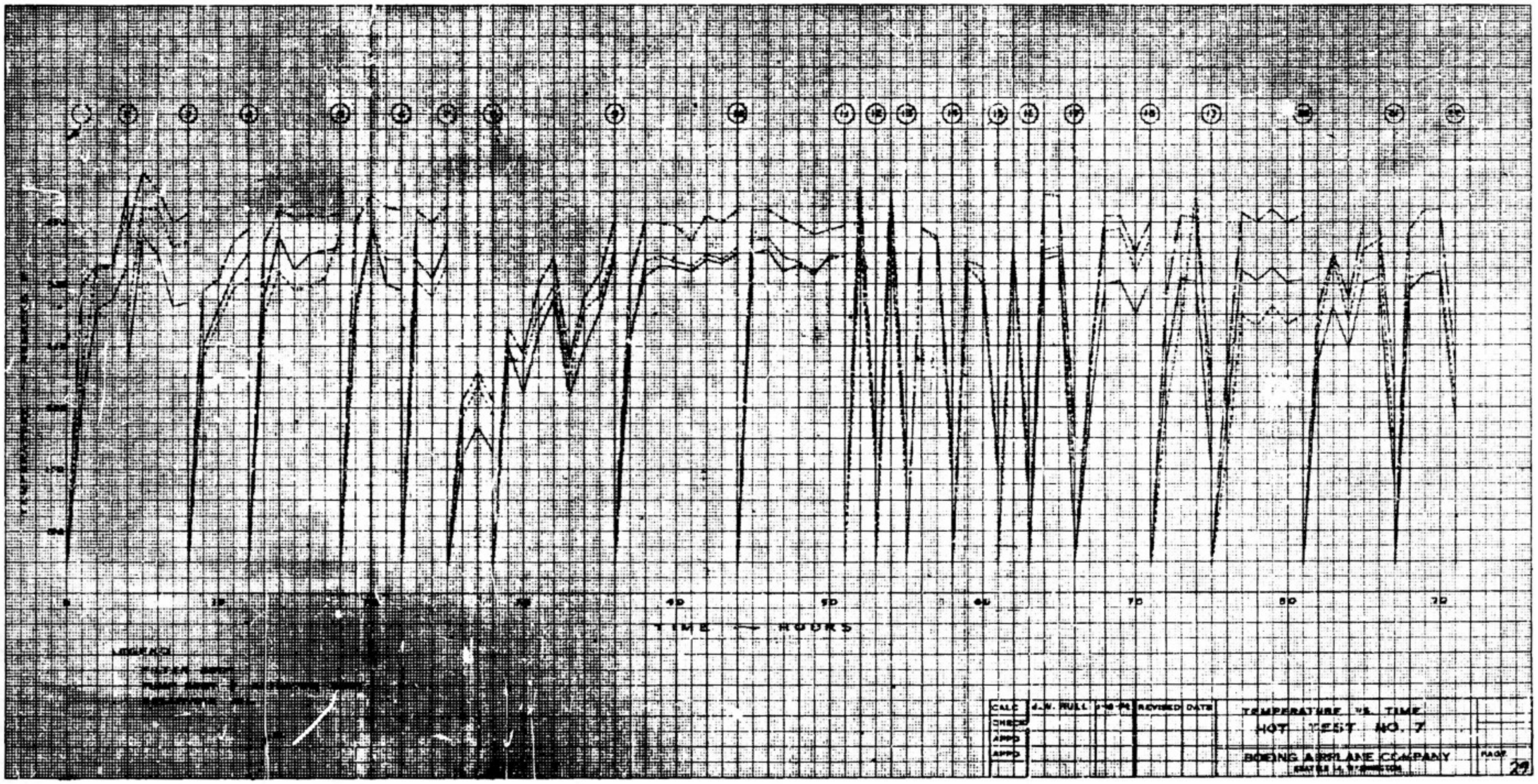
22 Discontinued Test

A. Accumulator precharge down to 1200 psi. AN6227-33 "O" ring slightly abraded and deformed.

B. Both AN6235-4A filter elements failed. (Total 28 hrs.)

C. The AN 6227-29 "O" rings in the test piston were badly split circumferentially. (Total 40 hrs. and 49,117 cycles).

D. The AN 6227-19 "O" rings, while leaking slightly (2 dps./min), were not badly deformed (total 40 hrs. and 49, 117 cycles).



TIME — HOURS
LEGEND
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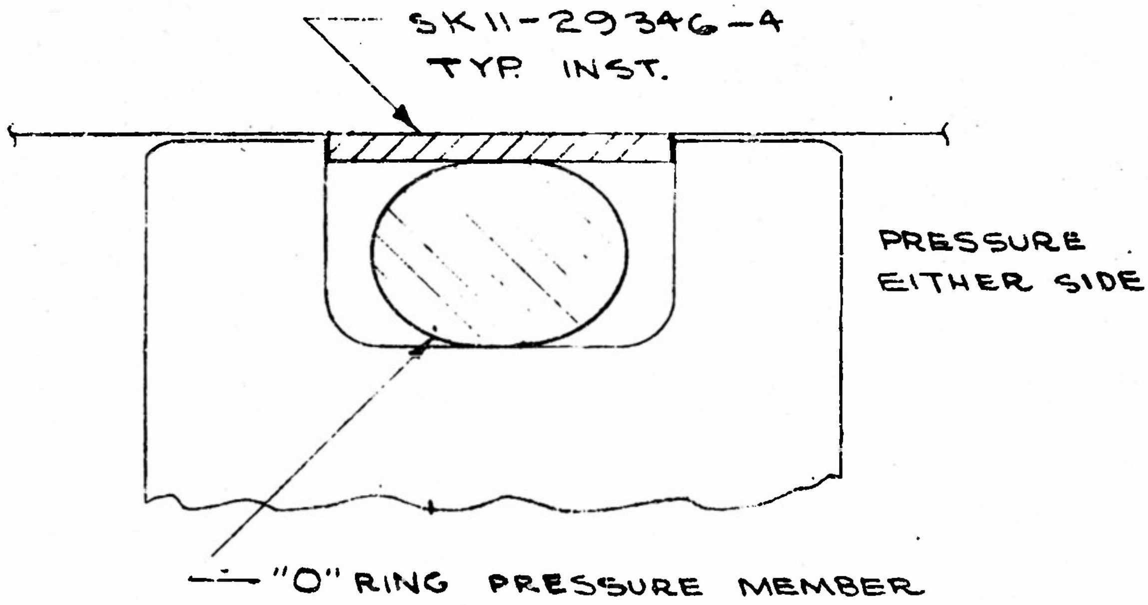
TEMPERATURE VS. TIME
HOT TEST NO. 7
BOEING AIRPLANE COMPANY
PAGE 29



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BOEING AIRPLANE COMPANY
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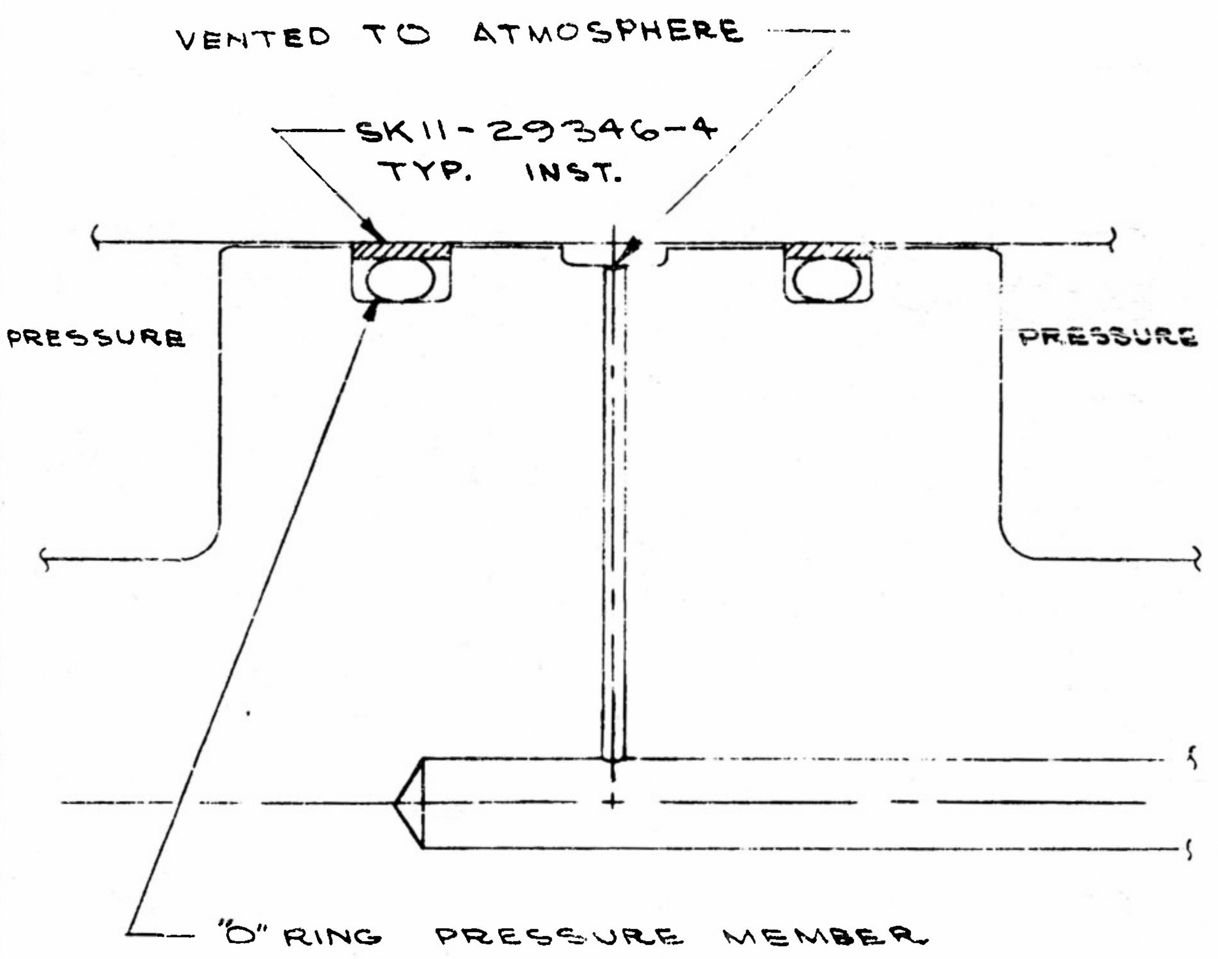

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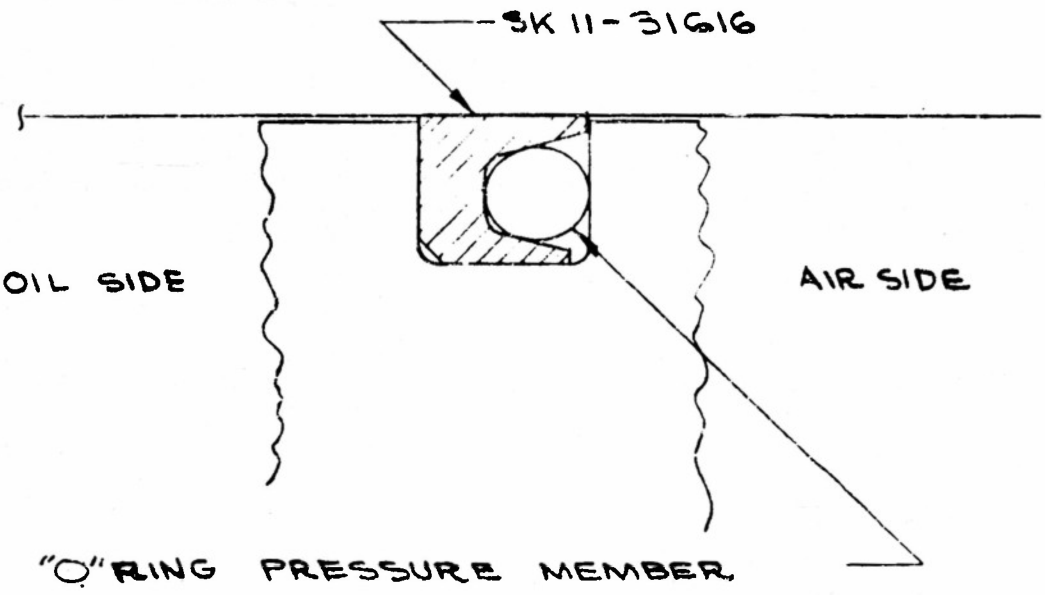
APPD					BOEING AIRPLANE COMPANY SEATTLE 14, WASHINGTON	PAGE 32



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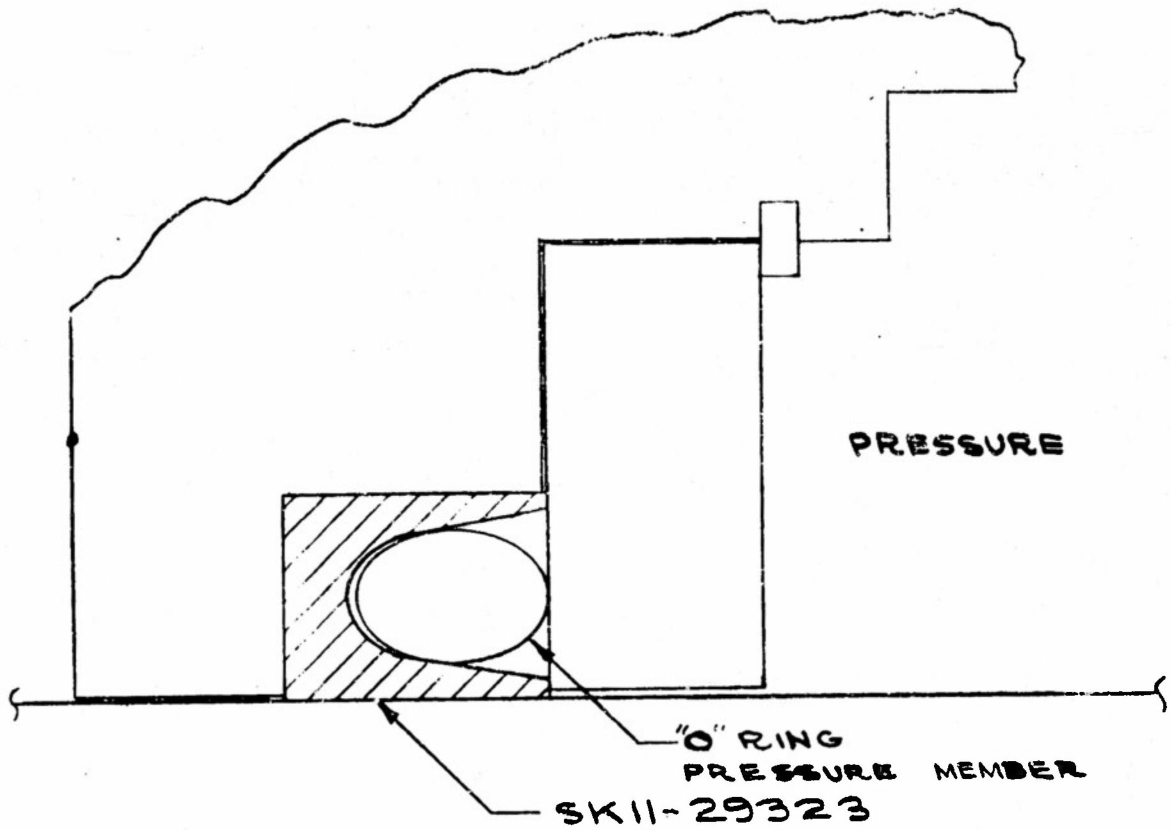

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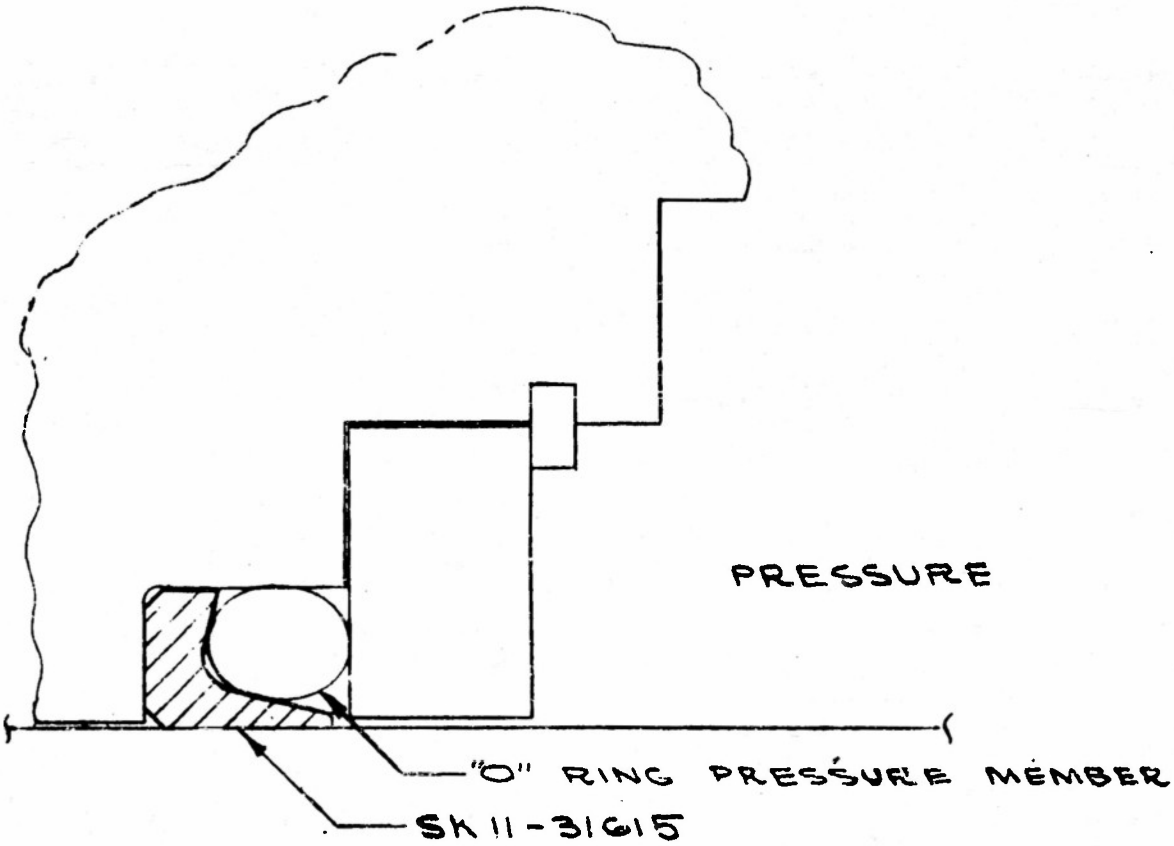

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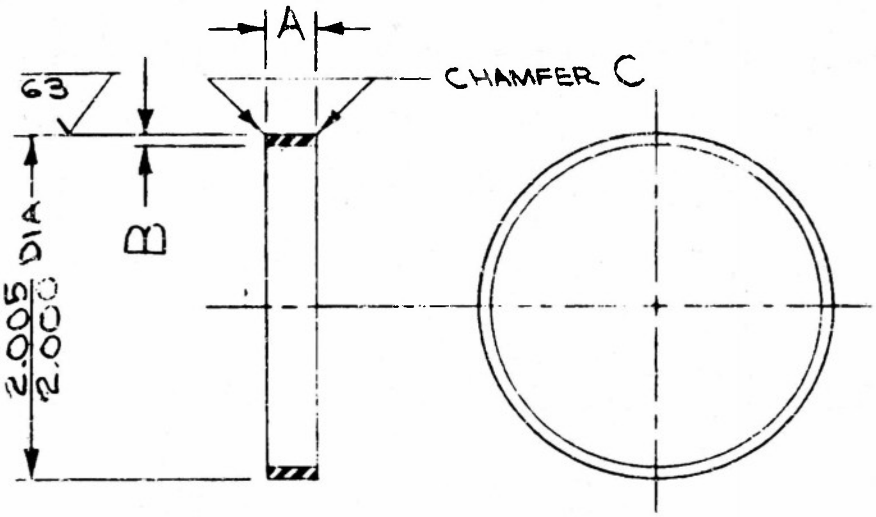
APPD					BOEING AIRPLANE COMPANY SEATTLE 14, WASHINGTON	PAGE 35

BAC 973 D-R3

ITEM NUMBER	DIMINSION A $\pm^{.005}_{.000}$	DIMINSION B $\pm^{.005}_{.000}$	DIMINSION C	USE WITH
-1	.270	.080	—	AN6230-1
-2	.230	.070	—	AN6230-1
-3	.230	.070	.02 X 45°	AN6230-1
-4	.270	.040	.015 X 45°	AN6227-29
-5	.145	.050	—	AN6230-1
-6	.150	.040	.015 X 45°	AN6230-1



SEAL RING

MAT. — TEFLON

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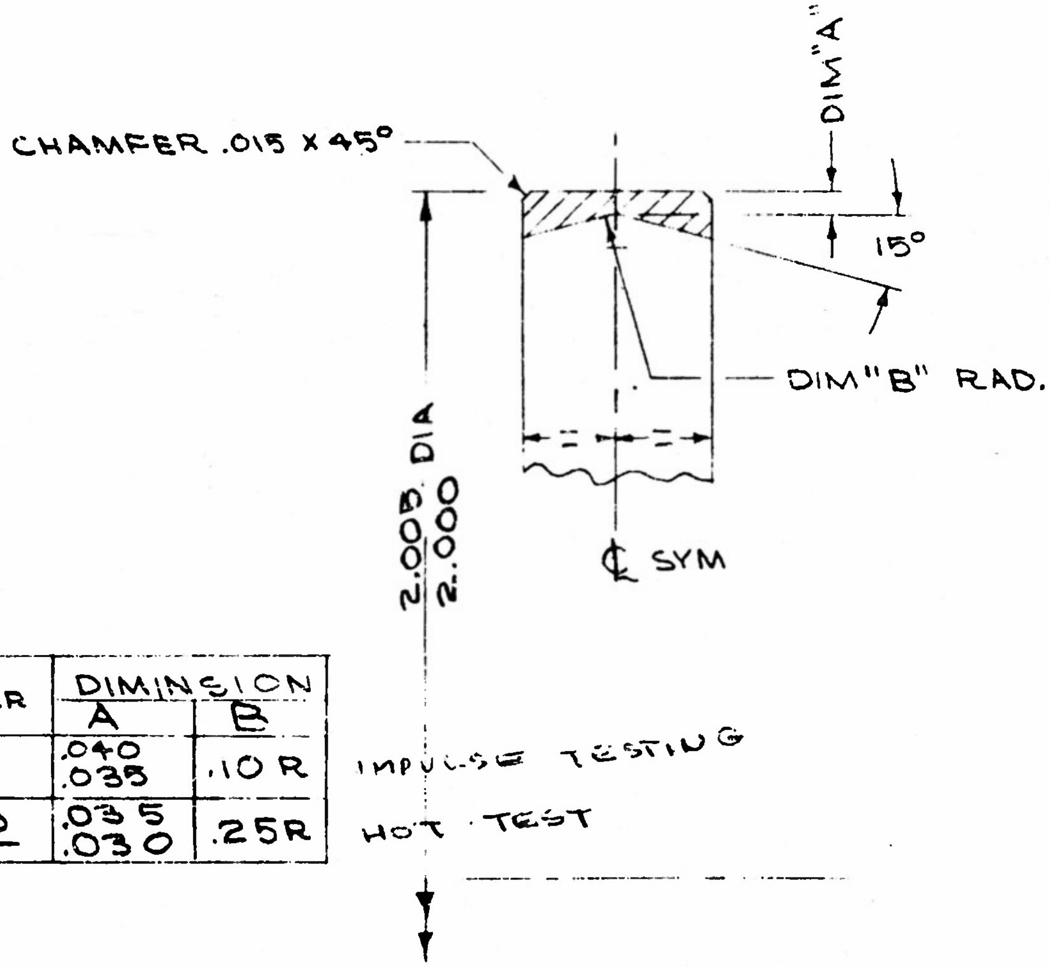
BAC 973 D R3



PART NUMBER	DIMINSION A	DIMINSION B
-1	.040 .035	.10 R
-2	.035 .030	.25R

IMPULSE TESTING

HOT TEST

SEAL - CAP STRIP

MAT. - TEFLON

SCALE - 4 TIMES SIZE

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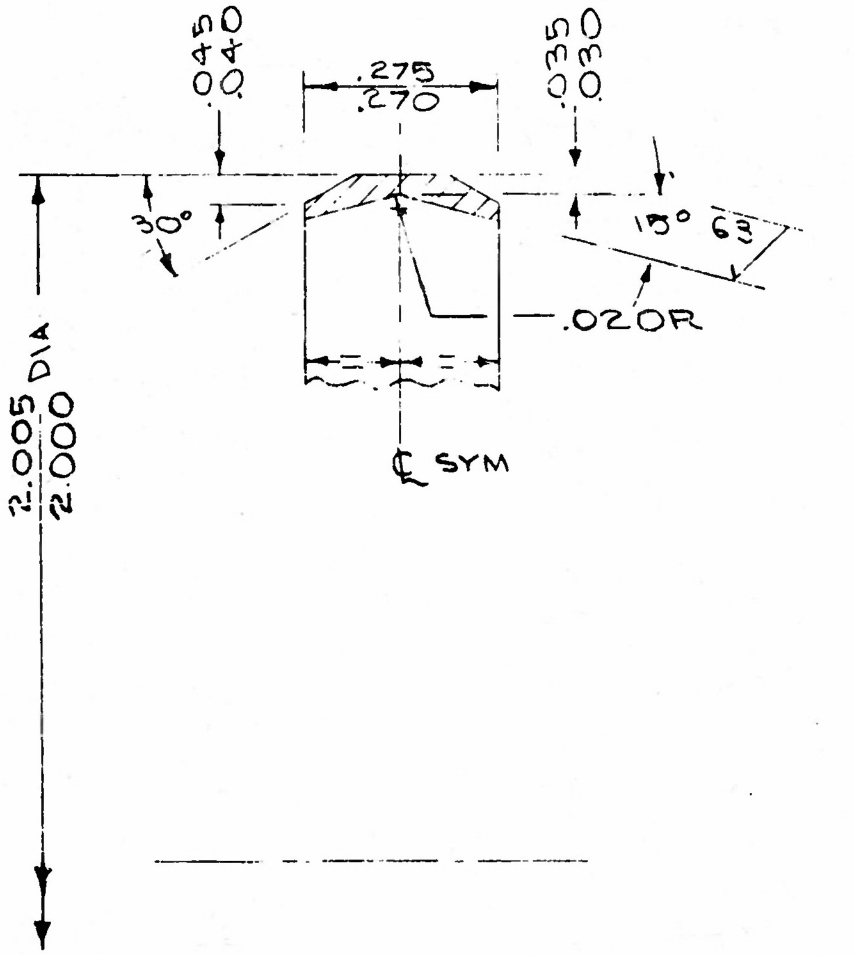
BAC 973 D-R3



SEAL - CAP STRIP

MAT. - TEFLON

SCALE - 4 TIMES SIZE

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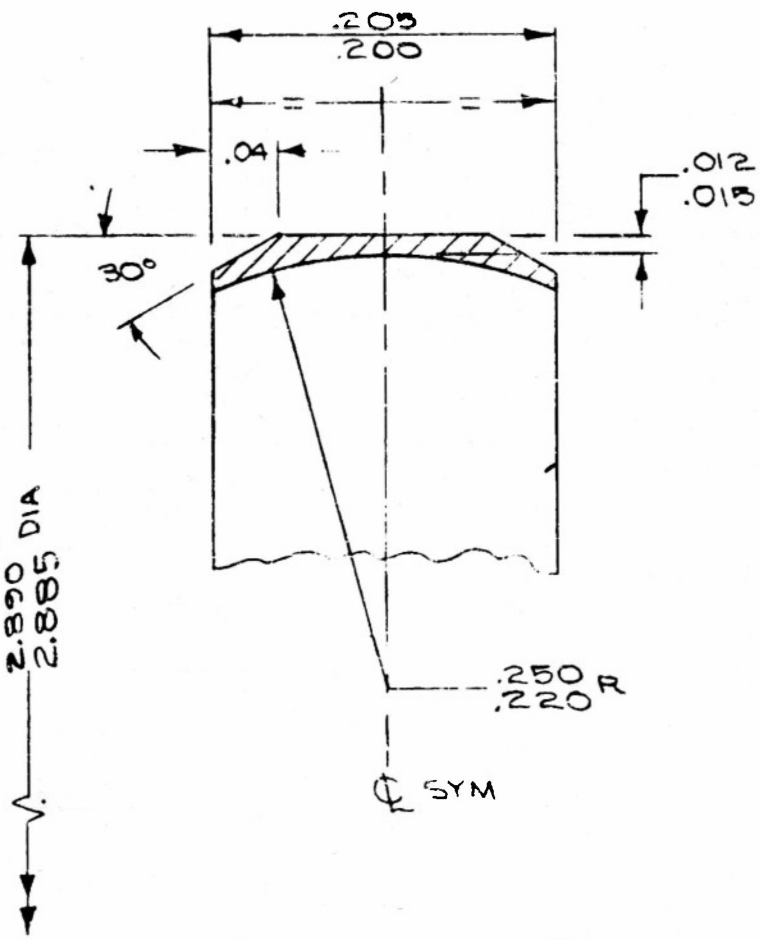
APPD					BOEING AIRPLANE COMPANY SEATTLE 14, WASHINGTON	PAGE 38



ACCUMULATOR SEAL

SCALE – 10 TIMES SIZE

MAT'L – TEFLON

63 √ FINISH ALL OVER

			REVISED	DATE	
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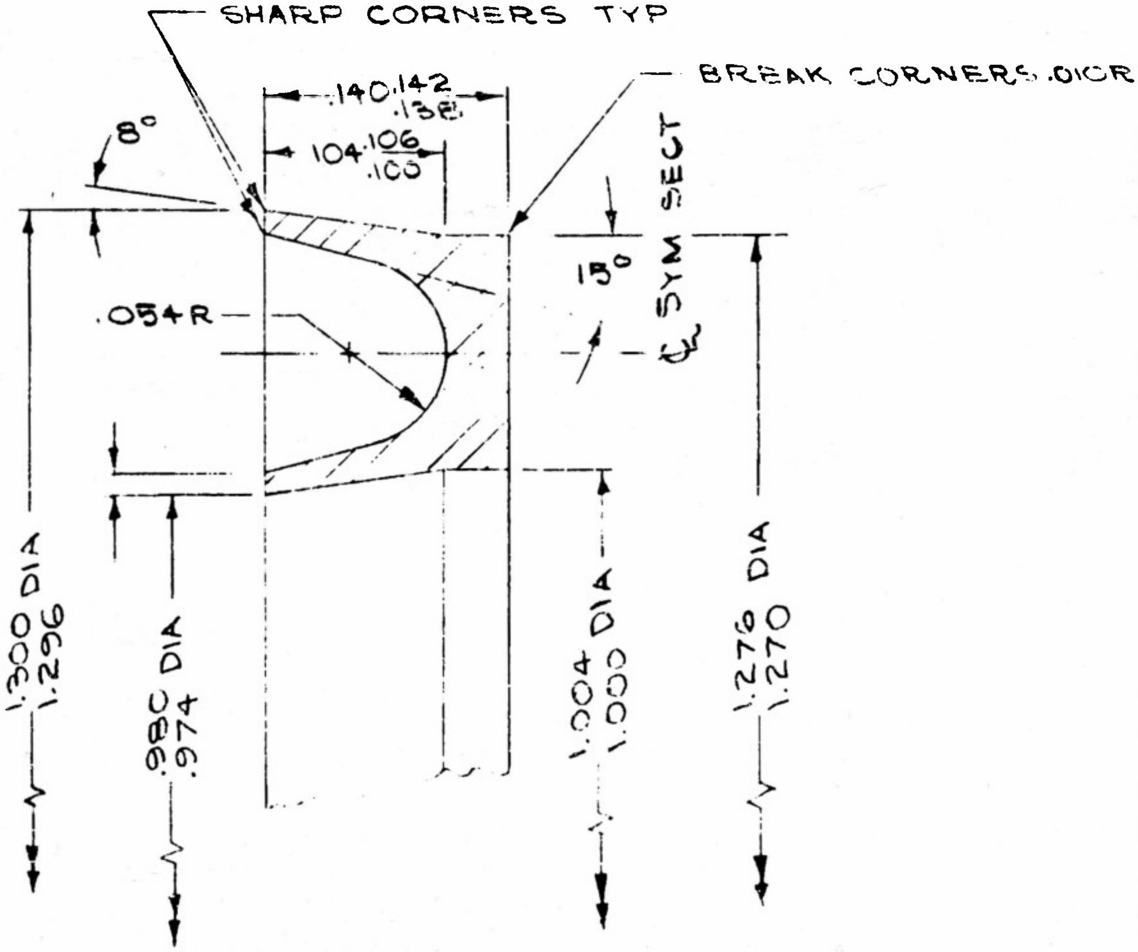
APPD					BOEING AIRPLANE COMPANY SEATTLE 14, WASHINGTON

BAC 573 D-R3

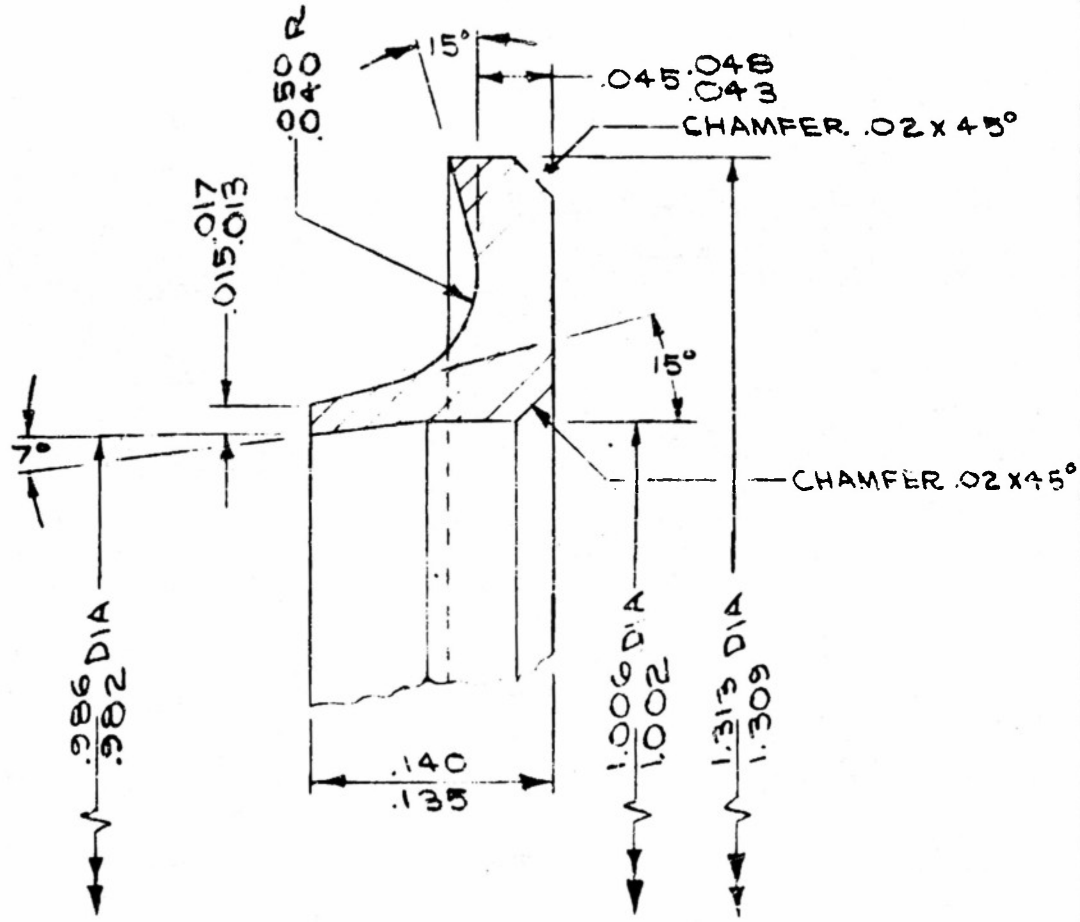


TEFLON SEAL

FOR 1" DIA ROD
USE WITH AN 6290-12 "O" RING
MAT'L – TEFLON
SCALE – 10 TIMES SIZE

CALC	A.E.E.	3/27/52	REVISED	DATE	SK 11-29323
CHECK					
APPD					BOEING AIRPLANE COMPANY SEATTLE 14, WASHINGTON
APPD					PAGE 40

BAC 973 D-R3



ROD GLAND SEAL

USE WITH AN 6227-19 SILASTIC
MAT'L - TEFLON
SCALE - 10 TIMES SIZE

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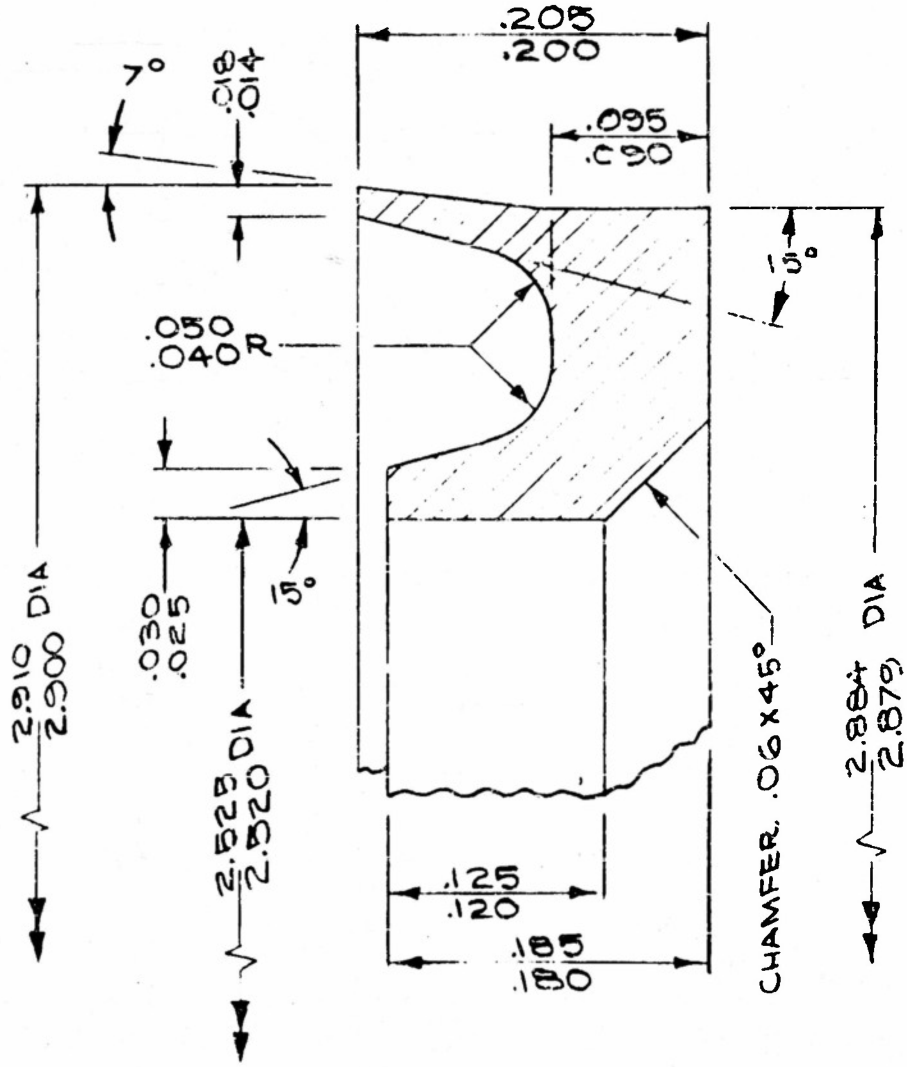
APPD					BOEING AIRPLANE COMPANY SEATTLE 14, WASHINGTON	PAGE 41
APPD						

BAC 973 D-R3



ACCUMULATOR SEAL

USE WITH AN 6230-9 "O" RING
MAT'L — TEFLON
SCALE — 10 TIMES SIZE

CALC			REVISED	DATE	SK 11-31616	
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APPD					BOEING AIRPLANE COMPANY SEATTLE 14, WASHINGTON	PAGE 42

BAC 973 D R3

APPENDIX 3

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MERRELL R. FENSKE, DIRECTOR

COLLEGE OF CHEMISTRY AND PHYSICS
THE PENNSYLVANIA STATE UNIVERSITY
STATE COLLEGE, PENNSYLVANIA

REPORT TO

MATERIALS LABORATORY WCRTR3, ENGINEERING DIVISION
WRIGHT AIR DEVELOPMENT CENTER

ON

SOME PROPERTIES OF SPEC. MIL-O-5606 HYDRAULIC FLUID AT ELEVATED TEMPERATURES

CONTRACT NO. AF33(038)18193

REPORT NO. PRL 6.3-DEC53

DECEMBER 30, 1953

TABLE OF CONTENTS

FOREWORD

This report has been prepared by the Petroleum Refining Laboratory of the College of Chemistry and Physics at the Pennsylvania State University under Air Force Contract AF33(038)18193. Mr. J. C. Mosteller, Materials Laboratory, WCRTR3, Engineering Division, Wright Air Development Center is the Acting Project Engineer for this work.

Research work for the Air Force on Fluids, Lubricants, Fuels and Related Materials by this Laboratory has been a continuous project since March 1941. The work from March 1941 to July 1945 was conducted under National Defense Research Committee Contract OEMsr408. Work from July 1945 to October 1951 was conducted under Navy Contract NOrd 7958(B).

SOME PROPERTIES OF SPEC. MIL-O-5606 HYDRAULIC FLUID AT ELEVATED TEMPERATURES

Summary. At the request of the Materials Laboratory, WCRTR-3 of the Wright Air Development Center this Laboratory has assayed in the laboratory some of the more important properties of Spec. MIL-O-5606 hydraulic fluids at elevated temperatures. These properties are summarized as a function of temperature on Table 1.

Volatility is an important property in high temperature applications of Spec. MIL-O-5606 fluids. Three characteristics in hydraulic system applications, directly related to the fluid's volatility, are: (1) vapor pressure, (2) inflammability, and (3) residual film formation due to evaporation. The upper limit of usefulness in a hydraulic system pressurized to one atmosphere would be of the order of 500°F., which is the initial boiling point of a typical Spec. MIL-O-5606 fluid at one atmosphere pressure. The flash point of a typical Spec. MIL-O-5606 fluid is about 220°F., which is approximately equal to the boiling point of the fluid at 10 mm. Hg. The spontaneous ignition temperature of the fluid is of the order of 500°F. Problems of tacky films arising from the extensive evaporation of exposed thin films of Spec. MIL-O-5606 fluids are related both to time and temperature. Undesirable tacky films appear after about 4 to 6 hours exposure at 200°F. without fluid scavenging. Control of tacky films is primarily a function of system design.

The viscosity-temperature characteristics of Spec. MIL-O-5606 fluid are good. Pump tests in commercial Vickers 3,000 p.s.i. piston pumps indicate that the viscosity level is adequate for successful operation over the entire range of -65° to +500°F. Lubricity studies show that the fluid has adequate lubricating properties for hydraulic pumps over this same temperature range. Volatility is probably the limiting factor in high temperature pump operation. It appears that fluid volatility may increase wear in pumps operating at temperatures above 400°F.

The thermal stability of typical Spec. MIL-O-5606 hydraulic fluids is excellent up to 500°F. In the temperature range of 450° to 500°F. there is some viscosity decrease due to thermal depolymerization of the polymeric thickener. There is, however, no evidence of volatile product formation, or of thermal decomposition products which are deleterious to the fluid's use or to overall fluid stability.

The oxidation behavior and stability are among the most important items in appraising the high temperature characteristics of Spec. MIL-O-5606 hydraulic fluid. The decrease with temperature in the fluid's induction period, or stable life during oxidation, is illustrated in Table 1. At elevated temperatures where the stable life of the fluid is very short and at lower temperatures when the stable life is exceeded, the oxidative deterioration becomes a function of the amount of oxygen or air in contact with the fluid and on the intimacy of this air-oil

contact. The data indicate that a Spec. MIL-O-5606 fluid can tolerate the assimilation of moderate quantities of oxygen at elevated temperatures without excessive deterioration of the fluid or troublesome corrosion of metals. It may be desirable, therefore, to pressurize with nitrogen, or seal with a diaphragm, hydraulic systems designed to have a bulk oil temperature in excess of about 200°F.

Oil change intervals in a closed system of this type could be scheduled to approximate the stable life of the fluid plus the time of operation during which the air leakage or entrainment into the fluid is estimated to be 100 to 200 cubic feet (at 32°F. and 760 mm. Hg) per five gallons of oil. It is believed that the assimilation by the fluid of the oxygen in 600 to 1,000 cubic feet of air per five gallons of fluid can be tolerated without causing the average hydraulic system to become inoperative from the standpoint of oxidative deterioration.

In accelerated laboratory tests copper, copper alloys, and silver cause a reduction of about 50 per cent in the stable life of a typical Spec. MIL-O-5606 fluid at 300°F. These metals are the most effective of those evaluated in this study in causing a decrease in the fluid's stable life. The fluid's stable life is the time interval (hours) during which oxygen is not significantly absorbed, or assimilated, by the fluid even though there is available ample oxygen and oxygen-oil contact. It is believed that none of the metals evaluated in this study should be excluded from aircraft hydraulic systems using Spec. MIL-O-5606 fluid solely on the basis of their catalytic effects in accelerating oxidation.

A high quality Spec. MIL-O-5606 hydraulic fluid does not corrode metals normally used in hydraulic systems. It has been established that a typical Spec. MIL-O-5606 fluid in a state of incipient oxidation does not corrode copper, aluminum, and steel at 500°F. On the basis of low temperature (250°F.) tests it is suggested that cadmium plate be eliminated from hydraulic systems. High temperature oxidation and corrosion tests indicate that it would be desirable to eliminate magnesium from hydraulic systems where temperatures of 250°F. or greater exist or are predicted, or where the fluid will be used to the point of incipient oxidation. This applies primarily to closed hydraulic systems where oxidized products including water will be in intimate contact with the metals of construction.

A number of miscellaneous physical properties have been included in this report primarily for use in design and engineering calculations. These properties include: specific heat, thermal conductivity, bulk modulus of elasticity as a function of temperature, density as a function of temperature, cubical coefficient of expansion, and viscosity as a function of temperature and pressure.

In general, these studies show that a high quality Spec. MIL-O-5606 fluid exhibits good overall stability at temperatures up to 500°F. under a variety of conditions. It should be emphasized that the quality of the Spec. MIL-O-5606 fluid used in this study in terms of

oxidation and corrosion stability, in particular, is better by at least a factor of two than the minimum quality fluid guaranteed by the Specification. The formulation of more specific limitations will require the testing of actual hydraulic system components and current Spec. MIL-O-5606 fluids.

Table 1

SUMMARY OF THE PROPERTIES OF A TYPICAL SPEC. MIL-0-5606 FLUID

TEMPERATURE, °F.	-65	-40	0	100	200	300	400	500
KINEMATIC VISCOSITY, CS.	2,000	487	103	14.2	5.3	2.9	1.9	1.4
VAPOR PRESSURE, MM. HG	-	-	<0.01	0.1	3.0	38	210	600
TACKINESS PROPERTIES OF EVAPORATED FLUID FILM AFTER 20 HOURS	O.K.	O.K.	O.K.	O.K.	BORDERLINE	POOR	POOR	POOR
THERMAL STABILITY	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	FAIR
OXIDATION AND CORROSION STABLE LIFE (SPEC. MIL-0-5606 CONDITIONS), HOURS	-	-	-	>10,000	3,000	60	<2(3)	<1(3)
LUBRICITY IN SHELL FOUR-BALL WEAR TESTER	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	-
ESTIMATED LUBRICITY FOR PISTON TYPE HYDRAULIC PUMP(1)	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	-
ESTIMATED PUMP DELIVERY (% OF RATED CAPACITY) FOR PISTON TYPE PUMP(1)	100	100	100	100	100	98	96	91
ESTIMATED PUMP PERFORMANCE BASED ON FLUID VOLATILITY(2)	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	POOR
CORROSION PROPERTIES WITHIN THE OXIDATION STABLE LIFE OF THE SPEC. MIL-0-5606 FLUID FOR:								
STEEL	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.
ALUMINUM	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.
COPPER	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.
BRONZE	-	-	-	-	O.K.	O.K.	-	-
MAGNESIUM	O.K.	O.K.	O.K.	O.K.	O.K.	BORDERLINE	POOR	POOR
SILVER-PLATED STEEL	-	-	-	-	O.K.	O.K.	-	-
LEAD	-	-	-	-	O.K.	O.K.	-	-
LEAD-INDIUM COATED SILVER-PLATED STEEL	-	-	-	-	O.K.	O.K.	-	-
DENSITY, GMS./CC.	0.89	0.88	0.86	0.83	0.79	0.75	0.71	-
BULK MODULUS OF ELASTICITY, P.S.I. X 10^{-5} (AVERAGE FOR 0 TO 10,000 P.S.I.)	3.6	3.4	3.2	2.7	2.2	1.7	1.2	0.7
SPECIFIC HEAT, B.T.U./LB./°F.	-	-	0.45	0.50	0.55	0.60	0.65	-
THERMAL CONDUCTIVITY, B.T.U./SQ.FT./HR./°F./FT.	-	-	0.081	0.079	0.076	0.074	0.071	-

(1) THESE DATA ARE BASED ON STUDIES IN A VICKERS MODEL PF-17-3911-10ZEL PISTON PUMP MADE WITH MINERAL OILS PREPARED TO EXHIBIT THE SAME VISCOSITY AND LUBRICITY LEVEL AT 100° TO 200°F. THAT IS CHARACTERISTIC OF SPEC. MIL-0-5606 IN THE 300° TO 500°F. TEMPERATURE RANGE.

(2) THESE DATA ARE BASED ON WEAR STUDIES CONDUCTED IN PISTON AND GEAR TYPE HYDRAULIC PUMPS USING LARGE CONCENTRATIONS OF VOLATILE HYDROCARBONS IN SPEC. MIL-0-5606 TYPE FLUIDS.

(3) THESE VALUES REFER TO THE INDUCTION PERIOD OR STABLE LIFE. THE ACTUAL USEFUL LIFE OF THE FLUID AT THIS TEMPERATURE IS A DIRECT FUNCTION OF THE RATE OF OXYGEN OR AIR LEAKAGE INTO THE FLUID OR HYDRAULIC SYSTEM. AS INDICATED IN TABLE 12 OF THIS REPORT, USEFUL LIVES OF 20 TO 40 HOURS CAN BE ACHIEVED IN THE TEMPERATURE RANGE OF 400° TO 500°F. AT MODERATE RATES OF AIR CIRCULATION OR AVAILABILITY.

PETROLEUM REFINING LABORATORY
COLLEGE OF CHEMISTRY AND PHYSICS

THE PENNSYLVANIA STATE UNIVERSITY
STATE COLLEGE, PENNSYLVANIA
DECEMBER 10, 1953

SOME PROPERTIES OF SPEC. MIL-O-5606 HYDRAULIC FLUID AT ELEVATED TEMPERATURES

Introduction. The Wright Air Development Center requested that this Laboratory evaluate the properties of Spec. MIL-O-5606 hydraulic fluid at elevated temperatures. Spec. MIL-O-5606 hydraulic fluid has been used over the past 10 years as the aircraft hydraulic fluid by the U. S. Air Force and the British and Canadian Air Forces. Indications are that Spec. MIL-O-5606 hydrocarbon-base hydraulic fluids have performed satisfactorily in a wide variety of uses over this period. The bulk of the data on the behavior of this hydraulic fluid has been obtained from use in conventional World War II piston engine aircraft.

Current developments in aircraft place emphasis on higher speeds and, therefore, higher ambient temperatures which result in higher hydraulic system temperatures. The hydraulic system temperature problem is intensified in some cases by the proximity of hydraulic lines to the combustion chamber and to the exhaust of turbine engines. With current emphasis on higher hydraulic system temperatures, a study of some of the practical limitations, temperature-wise, of Spec. MIL-O-5606 hydraulic fluid is of particular interest. Many of the data pertinent to a high temperature study of Spec. MIL-O-5606 hydraulic fluid had been obtained and discussed in reports on contracts prior to Contract AF33 (038)18193. These data along with current data are presented in this report.

Spec. MIL-O-5606, and earlier editions of this same specification (Spec. AN-O-366 and Spec. AN-VV-O-366b), are used interchangeably in this report except in discussions on wear and lubrication. Spec. MIL-O-5606 and Spec. AN-O-366 fluids contain tricresyl phosphate as the anti-wear additive while Spec. AN-VV-O-366b fluid does not contain a lubricity additive. For this reason any lubrication studies discussed are for the fluid containing the tricresyl phosphate.

Volatility. The volatility of Spec. MIL-O-5606 hydraulic fluid is one of the important properties determining its high temperature behavior. Three items in hydraulic system applications, related directly to volatility, are (1) vapor pressure, (2) inflammability, and (3) residual film formation due to evaporation.

A typical Spec. MIL-O-5606 hydraulic fluid is a blend comprising a mineral oil base stock, a less volatile mineral oil as the anti-tack component, a polymeric additive (viscosity index improver), an oxidation and corrosion inhibitor, and an anti-wear or lubricity additive. The mineral oil base stock constitutes the major portion of the hydraulic fluid. This mineral oil base stock is also the most volatile component of the fluid. Accordingly, it determines the general volatility level of the fluid. The Spec. MIL-O-5606 requirements place considerable restrictions on the volatility of the mineral oil base stock. Thus, the volatility characteristics of a typical commercially-prepared fluid meeting the specification can be considered to be of the same

order of magnitude for any commercial Spec. MIL-O-5606 fluid.

The vapor pressure-temperature relationship for a typical Spec. MIL-O-5606 type fluid is shown on Table 2 and Figure 1. These data show that this fluid has a vapor pressure of approximately 3 mm. Hg at 200°F. and 38 mm. Hg at 300°F. Expressing these vapor pressure data in another way, the fluid would begin to boil at about 500°F. and atmospheric pressure at sea level. Boiling would begin in an unpressurized system at 375°F. and at an altitude of 40,000 ft. (140 mm. Hg absolute pressure). Currently, pressurized hydraulic systems are being considered. On the basis of vapor pressure, a maximum temperature of about 500°F. could be tolerated in a hydraulic system pressured to 760 mm. The data shown on Table 1 indicate about a 20°F. spread between the initial boiling point and the 20 per cent distillation point. This is typical of the narrow boiling fractions commonly used as a base stock for Spec. MIL-O-5606 hydraulic fluid. Values of vapor pressure, or boiling point, intermediate to those shown on Table 1 can be obtained from the graph of the logarithm of absolute pressure versus the logarithm of the temperature as shown on Figure 1.

The volatility of mineral oils and most synthetic lubricants is closely related to inflammability properties as revealed by the open cup flash and fire points. The Spec. MIL-O-5606 limit on flash point is 200°F. The flash point for the sample used to obtain the vapor pressure data shown on Table 2 is 230°F.

The relationship between flash point, fire point, and vapor pressure is shown on Figure 2. These data include narrow boiling mineral oil fractions and some dibasic acid esters. There is relatively good correlation between the Cleveland open cup fire point and the initial Cottrell boiling point, or the 10 per cent distillation point when converted to 10 mm. Hg absolute pressure. The fire point is slightly lower than the 10 mm. Hg boiling point for values above 400°F. The correlation is good in the 200° to 400°F. region which includes the volatility range of Spec. MIL-O-5606 hydraulic fluid. The data on Figure 2 also show, for these narrow boiling mineral oil fractions and esters, that the spread between the open cup flash point and the fire point is about 10°F. per 100°F.

<u>Thin Film Evaporation.</u> Evaporation of the base stock from thin films of Spec. MIL-O-5606 fluid results in concentrating the polymeric additive in the residual film. Excessive base stock evaporation gives a tacky or sticky film. A high boiling component is added to the bulk of the mineral oil base stock as an anti-tack component to control the properties of the films left after extensive evaporation. Problems in the hydraulic system due to excessive evaporation could exist in portions of the system which are wetted with oil during operation, but which are not filled with oil during shut down periods and are open, or have access to substantial amounts of circulating air. Severe film tackiness in these portions of a hydraulic system could lead to malfunctioning of close clearance parts such as valves. This is strictly an evaporation phenomenon, and if the system

Table 2

VAPOR PRESSURE - TEMPERATURE RELATIONSHIPS FOR
SPECIFICATION AN-VV-O-366b HYDRAULIC FLUID

Test Fluid = PRL 1912 = Typical Commercially-Prepared
Specification AN-VV-O-366b Fluid

INITIAL BOILING POINT data obtained on new sample of
Specification AN-VV-O-366b fluid

20% DISTILLATION POINT data obtained on sample of
Specification AN-VV-O-366b fluid after distilling
off 20 volume per cent of the fluid.

ABSOLUTE PRESSURE, mm. Hg	TEMPERATURE, °F. Initial Boiling Point	20% Distillation Point
700	494	-
600	481	499
500	466	484
400	448	465
300	426	442
200	397	414
100	353	372
50	315	336
10	246	273
1	-	213

TEMPERATURE, °F.	ABSOLUTE PRESSURE, mm. Hg Initial Boiling Point	20% Distillation Point
475	558	450
450	405	330
425	297	237
400	210	162
375	146	107
350	97.5	67.0
325	63.0	40.0
300	38.2	21.5
275	21.9	11.9
250	11.3	4.6
225	5.3	1.7
200	3.0	-

PETROLEUM REFINING LABORATORY
COLLEGE OF CHEMISTRY AND PHYSICS

THE PENNSYLVANIA STATE UNIVERSITY
STATE COLLEGE, PENNSYLVANIA
MARCH 22, 1949

Figure 1 PRL 6.3-Dec53

VAPOR PRESSURE-TEMPERATURE RELATIONSHIPS FOR SPEC. AN-VV-O-366b HYDRAULIC FLUID

TEST FLUID: PRL 1912 = TYPICAL COMMERCIALLY-PREPARED SPEC. MIL-O-5606 TYPE FLUID.

△ = INITIAL BOILING POINT DATA OBTAINED ON A NEW SAMPLE.
○ = 20% DISTILLATION POINT DATA OBTAINED ON SAMPLE AFTER DISTILLING OFF 20 VOLUME PER CENT OF THE FLUID.

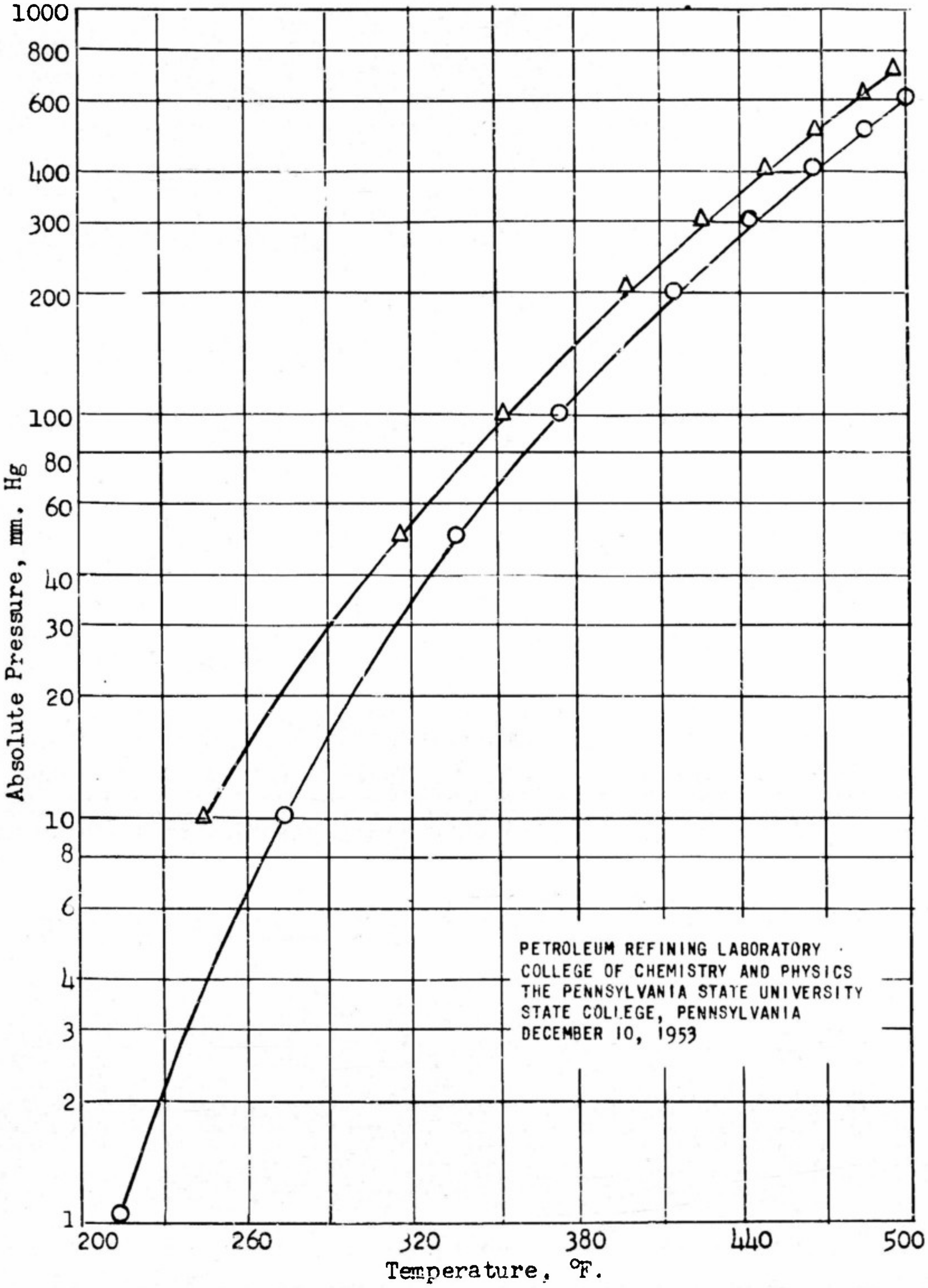
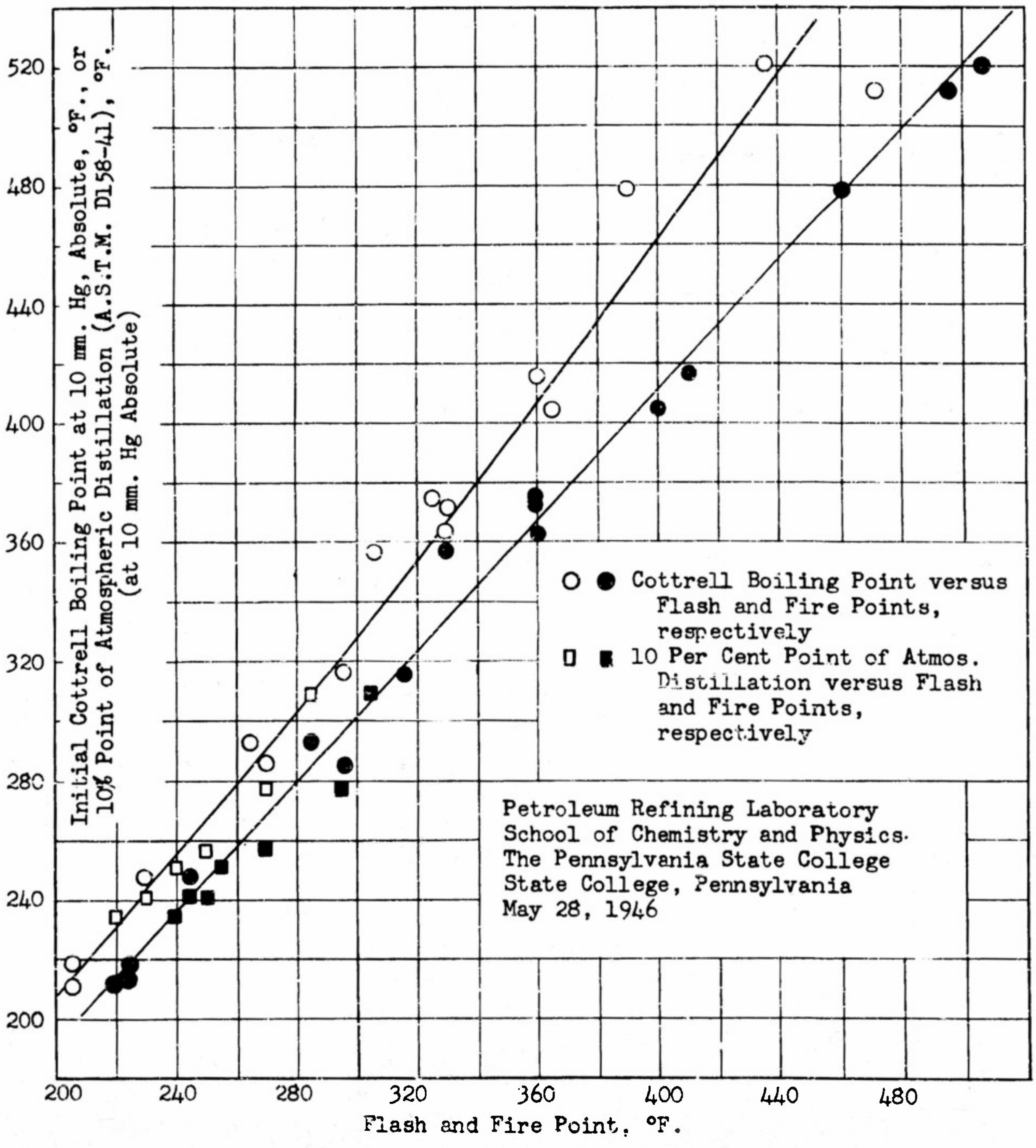


Figure 2

CORRELATION OF COTTRELL BOILING POINT, FLASH AND FIRE POINTS, AND DISTILLATION TEMPERATURE OF VARIOUS LIQUIDS



is closed, or otherwise arranged so that evaporation is minimized, then these problems of thin film tackiness do not arise.

This Laboratory developed a quantitative measure of evaporation and tackiness of thin films of hydraulic fluid. This technique has been applied to both Spec. MIL-O-5606 and Spec. 51-F-21 (Navy) hydraulic fluids. Two distinct operations are involved in the evaporation test. These techniques are described briefly in the following paragraphs. A more complete description of these tests is given in Formal Report No. 11 to the National Defense Research Committee dated March 1, 1946, pages 41 to 67.

The first portion of the test comprises evaporating a thin film. A one millimeter thick fluid film is evaporated for 80 hours in a flat steel cup at an oil film temperature of 190°F. The evaporation cup rests on the bottom of a glass beaker which is immersed in a constant temperature oil bath. Dry air at the rate of 5 liters per hour is passed over the surface of the oil film. At regular intervals the steel cups are removed from the bath and weighed on an analytical balance. The weight per cent oil evaporated can be determined from the weight change. The evaporation characteristics of each oil can then be represented by a curve of total weight per cent evaporation versus time.

An 80 hour test period is employed as a reference point. At the end of this period most of the more volatile components of the base stock of a typical Spec. MIL-O-5606 fluid have evaporated, and the rate of evaporation has reached a slow or negligible rate. This appears to be a desirable point at which to compare weight per cent evaporated and film tackiness.

The second portion of the evaporation test comprises a simple vacuum distillation of a portion of test fluid. The vacuum distillation is carried to the same value of weight per cent distilled as the value of weight per cent evaporation noted in the first portion of the test. The temperature of the vacuum distillation is kept below 400°F. to prevent any viscosity changes due to thermal decomposition or cracking. The properties of the residue from the distillation are then considered to represent or typify the residue from the 80 hour evaporation test. The 100°F. viscosity of the distillation residue is determined. This viscosity is considered to be approximately equal to the viscosity of the oil film after 80 hours' evaporation in the steel cup. It is believed that viscosity is the property that relates most closely to film tackiness.

A complete discussion of the above test techniques for measuring tackiness on a quantitative basis is in Report PRL 3.4-Sep45 entitled "PREPARATION OF SPECIFICATION O.S. 2943 HYDRAULIC FLUIDS WITH IMPROVED TACKINESS CHARACTERISTICS" and dated September 27, 1945. Report PRL 106.11, June 1945 entitled "SPECIFICATION AN-VV-O-366b HYDRAULIC FLUIDS WITH IMPROVED TACKINESS CHARACTERISTICS" describes the improvements that can be made in the tackiness, or residual film viscosity, by

using more effective anti-tack components of the dibasic acid ester type. The improvements discussed in these previous reports have been achieved without altering the overall specification limits on fluid properties with the possible exception of slight increases in rubber swelling.

Evaporation characteristics for typical Spec. MIL-O-5606 base stock components are shown on Figure 3. These data clearly indicate that the thin film evaporation rates at temperatures of 190°F. and higher are rapid for the bulk base stock (Winkler base oil) and still appreciable for the anti-tack component (Voltesso 36) of a good quality Spec. MIL-O-5606 fluid. Evaporation data for a typical dibasic acid ester (di-2-ethylhexyl sebacate) in the same viscosity grade as the mineral oil anti-tack component (Voltesso 36) are shown as a basis of comparison.

Evaporation data for four commercial Spec. AN-VV-O-366b fluids are shown on Figure 4. Composition, evaporation, and film viscosity data for the fluids shown on Figure 4 are tabulated on Table 3. The film viscosity illustrates the relative tackiness of the residual films after evaporation much more effectively than data showing simply weight per cent evaporation. These data indicate that there was considerable variation in the evaporation and tackiness characteristics of commercial Spec. AN-VV-O-366b hydraulic fluids. These fluids were formulated in 1944. It is of interest to note, however, that the requirements on evaporation and tackiness in the current Spec. MIL-O-5606 are the same as those in Spec. AN-VV-O-366b. A range in film viscosity similar to that illustrated on Table 3 would be anticipated from current commercial Spec. MIL-O-5606 fluids.

As hydraulic system temperatures increase, it may be desirable to consider placing more restrictive limits on evaporation and tackiness. Current limits in the specification are based on a touch test.

Viscosity-Temperature Characteristics. A complete viscosity-temperature curve for a typical Spec. MIL-O-5606 hydraulic fluid (PRL 2883) for the range of -65°F. to +300°F. has been experimentally determined and is shown in Figure 5. PRL 2883 is a typical commercial Spec. MIL-O-5606 hydraulic fluid prepared by the Standard Oil Company of New Jersey. The fluid has a viscosity of 2.98 centistokes at 298°F. and and 2,000 centistokes at -65°F. Mineral oils, in general, appear as straight lines on the ASTM viscosity-temperature chart. However, fluids of the Spec. MIL-O-5606 type exhibit a slight curvature at temperatures below about 0°F. which leads to higher values than predicted from a straight line extrapolation in this low temperature region. The high temperature viscosity values have been predicted to 450°F. by a straight line extrapolation from the 210° and 298°F. measured values.

Improved evaporation characteristics are obtained, in general, at the expense of viscosity-temperature characteristics and low temperature viscosity. That is, the inclusion of higher concentrations of the same anti-tack component results in poorer viscosity-temperature characteristics. Blending curves showing the effects of increasing the anti-

Figure 3

EVAPORATION CHARACTERISTICS OF SPEC. MIL-0-5606 TYPE COMPOSITIONS AT A TEMPERATURE OF 1[illegible]0°F. AND AN INITIAL FILM THICKNESS OF 1.00 MM.

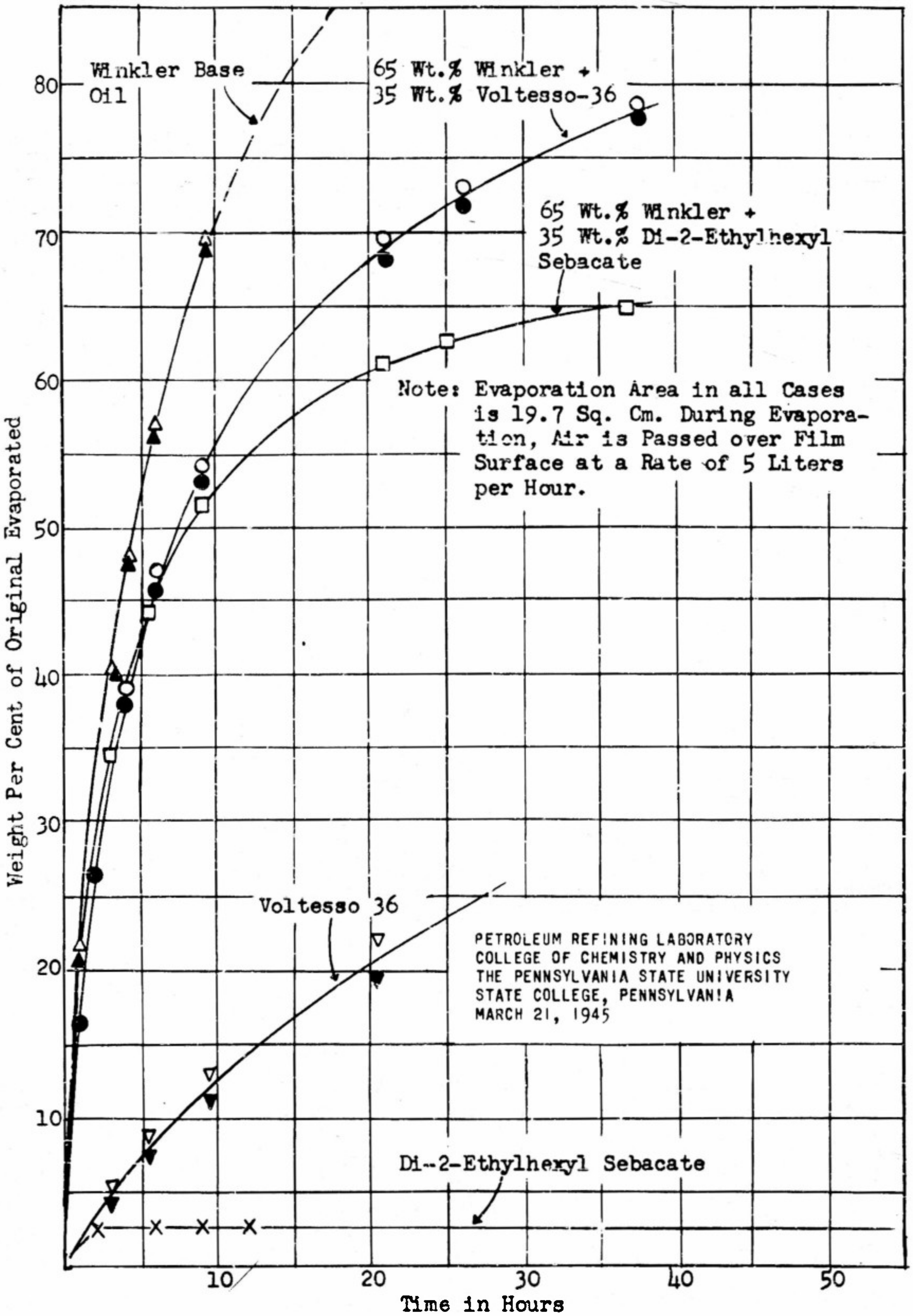


Figure 4

THIN FILM EVAPORATION CHARACTERISTICS OF SEVERAL SPECIFICATION AN-VV-O-366b FLUIDS FROM VARIOUS COMMERCIAL SOURCES

ALL TESTS CARRIED OUT AT AN INITIAL FILM THICKNESS OF 1.00 MM. AND AN AREA OF 19.7 SQUARE CM. THE OIL IS MAINTAINED AT A TEMPERATURE OF 190 ± 1°F., AND DURING EVAPORATION DRY AIR IS PASSED OVER THE FILM AT A RATE OF APPROXIMATELY 5 LITERS PER HOUR.

VISCOSITY AND EVAPORATION PROPERTIES ARE SHOWN ON TABLE 3.

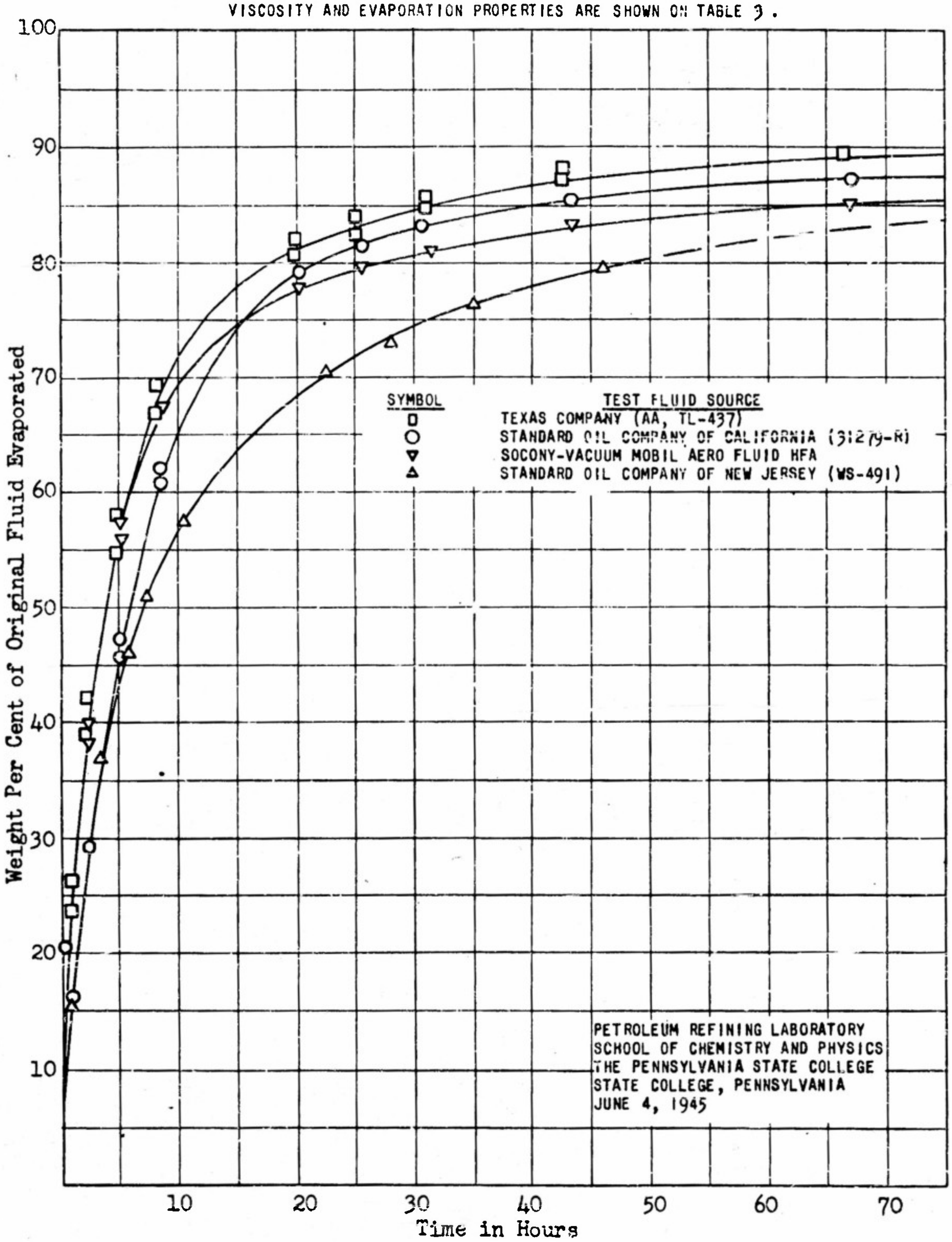


Table 3

TACKINESS EVALUATION OF SEVERAL IMPROVED AND COMMERCIAL AN-VV-O-366b FLUIDS

ALL TESTS CARRIED OUT AT AN INITIAL FILM THICKNESS OF 1.00 MM. AND AN AREA OF 19.7 SQUARE CM. THE OIL IS MAINTAINED AT A TEMPERATURE OF 190 ± 1°F., AND DURING EVAPORATION DRY AIR IS PASSED OVER THE OIL FILM AT A RATE OF APPROXIMATELY 5 LITERS PER HOUR.

PRL NO.	- -COMPOSITION OF FLUID, WT.% - - ACRYLOID 858	VOLTESSO 36	WINKLER	CENTISTOKE VISCOSITY +130°F.	-40°F.	FILM PROPERTIES AFTER EVAPORATION OF A 1 MM. FILM AT 190 ± 1°F. FOR 80 HOURS: WT.% EVAPORATED	POLYMER CONC., WT.%(2)	FILM VISCOSITY AT 100°F., CS.
	PRESENT BASE STOCKS OR EQUIVALENT							
(1)	7.0	18.6	74.4	10.0	480	34.0	43.7	3621
2229	6.1	32.9	61.0	9.7	603	79.5	29.7	885
	COMMERCIAL SAMPLES FROM VARIOUS SOURCES							
2119	SOCONY-VACUUM, MOBIL AERO FLUID HFA			10.0	435	85.5	53.8	8025
1848	STANDARD OIL COMPANY OF CAL. - NO. 31279-R			10.2	469	87.5	62.4	48000
1928	TEXAS COMPANY - NO. AA, TL-437			10.3	383	90.0	78.3	308000
1912	STANDARD OIL COMPANY OF N. J. - WS-451			10.1	454	84.0	48.8	3800

(1) FLUID COMPOSITION TYPICAL OF SPECIFICATION AN-VV-O-366B FLUIDS NOW BEING PREPARED.
(2) FINAL POLYMER CONCENTRATION FOR COMMERCIAL SAMPLES CALCULATED BY ASSUMING EACH FLUID TO HAVE AN INITIAL POLYMER CONCENTRATION OF 7.8 WEIGHT PER CENT.

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JUNE 4, 1945

tack component concentration in typical Spec. MIL-O-5606 and Spec. 51-F-21 (Navy) hydraulic fluids are shown on Figure 6. These data are for Voltesso 36 as the anti-tack component. Voltesso 36 is a typical naphthenic mineral oil suitable as an anti-tack component.

It should be emphasized that the low temperature viscosity scales on Figure 6 are accurate for only the compositions having an 80:20 base stock ratio of Winkler base oil to anti-tack component. There are reasonable deviations in the viscosity-temperature characteristics for blends having other ratios of base oil to anti-tack component. This deviation is illustrated in Table 4.

Table 4

VISCOSITY CHARACTERISTICS OF FLUIDS CONTAINING VARIOUS CONCENTRATIONS OF ANTI-TACK COMPONENT

Test Fluid Composition, Wt.% Light Base Oil	Anti-Tack (Voltesso 36)	Acryloid Polymer	Measured Visc., cs. at 130°F.	Measured Visc., cs. at -40°F.	Predicted -40°F. Visc. from Figure 6, cs.
92.0	0	8.0	10	330	460
83.2	9.3	7.5	10	395	490
74.6	18.6	6.8	10	500	500
65.6	28.1	6.3	10	605	590
55.5	38.7	5.8	10	750	640
47.4	47.4	5.2	10	970	690

Table 4 also illustrates the advantages in terms of the concentration of anti-tack component that can be gained by allowing a -40°F. viscosity of 750 centistokes instead of 500 centistokes.

High Temperature Pump Operation. Lubrication and volumetric efficiency are two important items in the operation of hydraulic pumps at high temperatures. Direct measurement of these properties is very difficult because of the lack of proven high temperature pumps. There have been indications that in the temperature range above 300°F. certain mechanical problems with currently available pumps retard or prohibit fluid testing. Therefore, another approach to lubrication and volumetric efficiency tests has been used. Lubricity and viscosity of high temperature hydraulic fluids can be measured in laboratory equipment. These measured properties at the desired temperatures can then be built into experimental fluids in the range of 100° to 200°F. These experimental fluids can then be tested in a pump under lower temperature conditions where no mechanical problems are anticipated.

Figure 5

VISCOSITY-TEMPERATURE CURVE FOR A TYPICAL SPEC. MIL-O-5606 HYDRAULIC FLUID FOR THE TEMPERATURE RANGE OF -65°F. TO +300°F.
Test Fluid = PRL 2883, a typical commercial Spec. MIL-O-5606 prepared by the Standard Oil Company of New Jersey

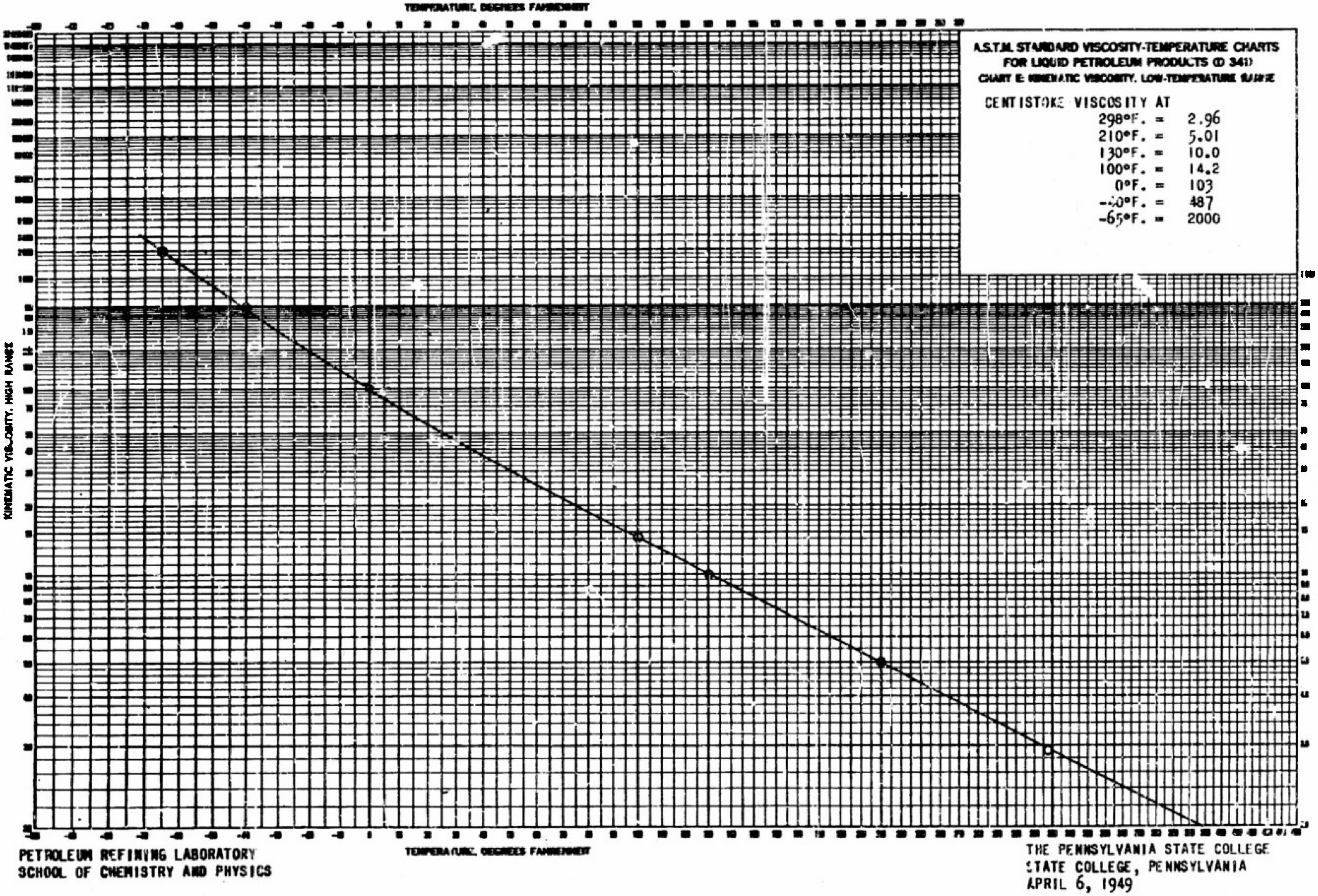
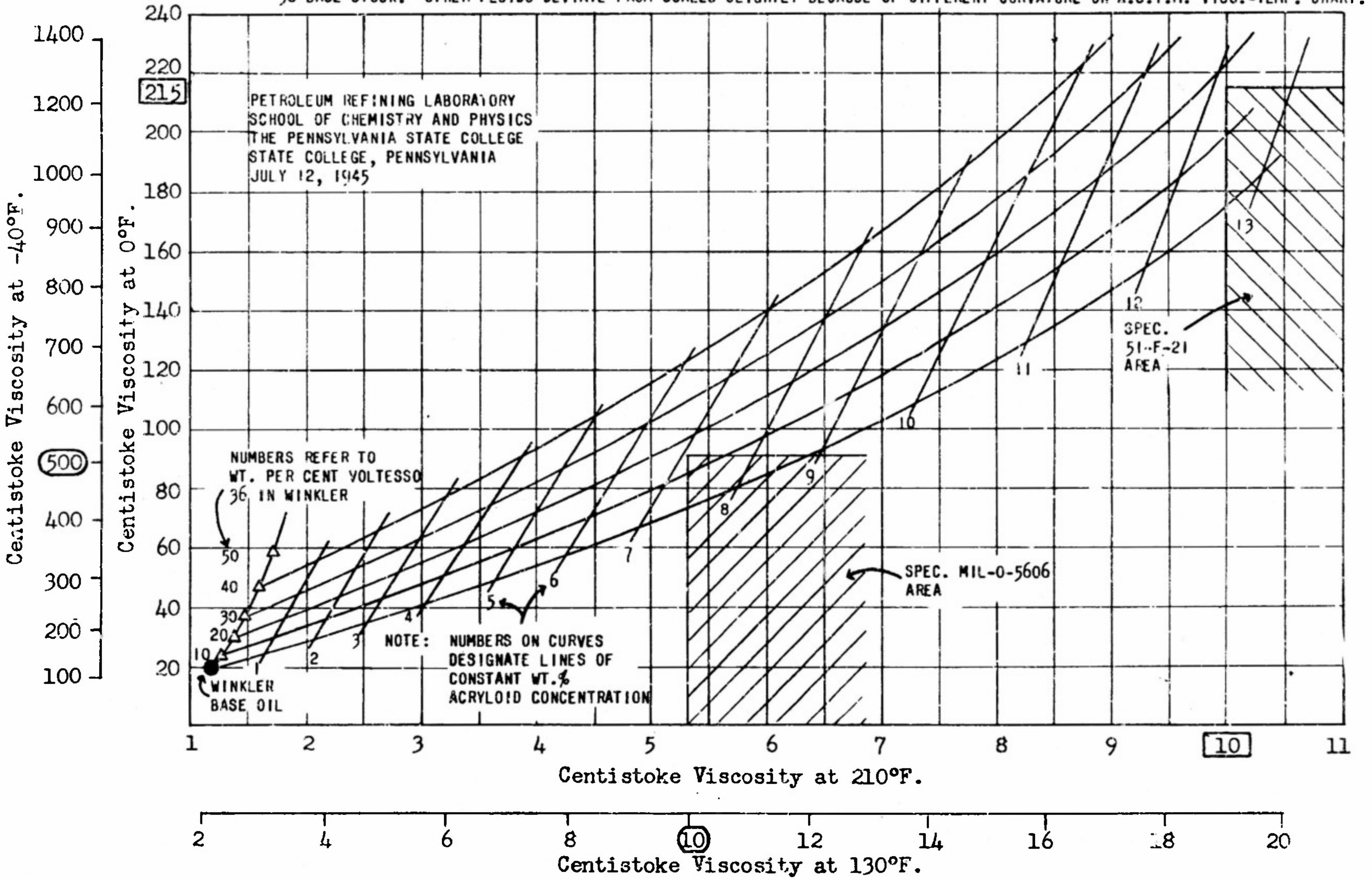


Figure 6

BLENDING CHARACTERISTICS OF ACRYLOID 858 IN WINKLER BASE OIL
EMPLOYING VOLTESSO 36 AS AN ANTI-TACK COMPONENT

NOTE: VISCOSITY SCALES FOR 130°F. AND -40°F. VALUES APPLY ONLY TO THOSE BLENDS CONTAINING AN 82:18 RATIO WINKLER-VOLTESSO 36 BASE STOCK. OTHER FLUIDS DEVIATE FROM SCALES SLIGHTLY BECAUSE OF DIFFERENT CURVATURE ON A.S.T.M. VISC.-TEMP. CHART.



Tests reported in previous Formal Reports to the National Defense Research Committee indicate that Spec. AN-VV-O-366b hydraulic fluids (without an anti-wear additive) operate satisfactorily in a Pesco 349 gear type pump at a viscosity level of 3.5 centistokes. The current study has emphasized viscosities below 3.5 centistokes at the test temperature.

The test fluids used in this study are mineral oil fractions containing an anti-wear additive and an oxidation inhibitor. The compositions of these test fluids, PRL 3414 and PRL 3415, are in Table 6. A comparison of the viscosities and volatilities of the mineral oil compositions and a typical commercial Spec. MIL-O-5606 hydraulic fluid are shown on Table 5.

Table 5

VISCOSITY AND VOLATILITY PROPERTIES OF SEVERAL MINERAL OIL COMPOSITIONS

Test Fluid	C.O.C. Fire Point, °F.	Temperature, °F. at Which Indicated Viscosity Value is Obtained			
		3.0 cs.	2.0 cs.	1.5 cs.	1.0 cs.
Commercial Spec. MIL-O-5606	235	295	390	485	-
PRL 3414	230	107	145	178	240
PRL 3415	235	72	109	142	203

The mineral oil fractions, PRL 3414 and PRL 3415, have viscosities of 1.0 to 3.0 centistokes in the range of 100° to 200°F. The commercial Spec. MIL-O-5606 hydraulic fluid has viscosities of 3.0 to 1.0 centistokes between 290°F. and the initial boiling point of the fluid (approx. 500°F.). The mineral oil fractions and the Spec. MIL-O-5606 fluid have about the same volatility properties.

The effect of bulk oil temperature on the wear characteristics measured by the Shell four-ball wear tester, of a typical Spec. 51-F-21 fluid and a Spec. 51-F-21 type hydraulic fluid without tricresyl phosphate, are shown on Table 9. This series of tests has not been conducted with a Spec. MIL-O-5606 hydraulic fluid. It should be noted that the ingredients of Spec. 51-F-21 and Spec. MIL-O-5606 fluids are essentially the same except that the Spec. MIL-O-5606 does not contain a rust inhibitor. Spec. MIL-O-5606 also contains less polymeric additive and a lower anti-wear additive concentration. It is noteworthy that there is no appreciable increase in wear with temperature for either blend. The data for a Spec. MIL-O-5606 fluid would be expected to follow quite closely the data for the Spec. 51-F-21 fluid. Thus, the wear properties of Spec. MIL-O-5606 type fluids at temperatures up to at least 400°F. would be expected to parallel the wear properties

of PRL 3414 and PRL 3415 in the 100° to 200°F. test region. Wear data for these test fluids at 167°F. in the Shell four-ball wear testing machine are shown on Table 6.

Table 6

WEAR CHARACTERISTICS OF SOME LOW VISCOSITY HYDRAULIC FLUIDS

Tests Conducted in the Shell Four-Ball Wear Tester.

Test Conditions Include: Test Time = 1 Hr.; Test Temp. = 75°C. (167°F.); Test Speed = 850 r.p.m.; Steel Balls = SKF Industries Grade #1 (0.5 inch Diameter) Steel Ball Bearings, PRL Batch #10.

PRL No.	Test Fluid Composition in Wt.%	Visc. at 100°F. cs.	Average Wear Scar Diameter, mm. Steel-on-Steel Bearing Surfaces 1 kg.	10 kg.	40 kg.
3115	Commercial Spec. MIL-O-5606 Hydraulic Fluid	14.2	0.16	0.22	0.62
3414	0.4 Paranox 441 + 5.0 Tricresyl Phosphate in XCT White Oil(1)	3.27	0.14	0.20	0.44
3415	0.4 Paranox 441 + 5.0 Tricresyl Phosphate in Kendall C-13(2)	2.18	0.15	0.48	0.45

(1) Narrow boiling fraction of highly refined naphthenic gas oil obtained from the Standard Oil Company of New Jersey.
(2) Narrow boiling fraction of Pennsylvania gas oil obtained from the Kendall Refining Company.

The behavior of PRL 3414 and PRL 3415 in the Vickers piston pump is shown on Table 8. The pump operated satisfactorily throughout this series of tests. The pump used for this series of tests is a standard production model. A typical Spec. MIL-O-5606 fluid was used to establish a basis for volumetric efficiency at 100°F. The volumetric efficiency as a function of viscosity is shown on Table 7.

Table 7

VOLUMETRIC EFFICIENCY VERSUS FLUID VISCOSITY IN A VICKERS PF-17-3911-10ZEL PISTON PUMP

Fluid Viscosity, Centistokes	Volumetric Delivery, g.p.m.	Per Cent of Maximum Delivery(1)
14.2	3.10	100
3.3	3.04	98
2.2	3.00	97
1.4	2.89	93
1.1	2.76	89

(1) Volumetric delivery with typical Spec. MIL-O-5606 fluid at 100°F. test temperature is considered 100% of maximum delivery.

These data indicate that currently available standard hydraulic pumps can be operated successfully with relatively low viscosity fluids having good lubricity.

The limitation in high temperature operation with Spec. MIL-O-5606 fluid may stem from volatility. That is, the lubricity and viscosity properties of Spec. MIL-O-5606 fluid are adequate up to the 400° to 500°F. temperature range. The initial atmospheric boiling point of a typical Spec. MIL-O-5606 is about 500°F. Some problems, such as high wear and cavitation, might be anticipated in the 400° to 500°F. region.

This Laboratory has conducted Pesco gear pump and wear studies with typical hydrocarbon-base fluids containing 30 weight per cent of a low boiling hydrocarbon such as hexane or isooctane. These studies are described in report PRL 3.35-May47. They were conducted at temperatures approximately 30° to 40°F. below the normal boiling point of the volatile constituent without difficulty. Moderately high wear was noted in both the Pesco gear pump and the Shell four-ball wear testing machine under these conditions. The determination of the actual high temperature limit of operability of Spec. MIL-O-5606 fluid, therefore, awaits the development of adequate high temperature pumps.

Thermal Stability. Thermal stability tests have been conducted at 500°F. on various components of, as well as a complete, Spec. MIL-O-5606 hydraulic fluid. These thermal stability data are in Table 10. Data for di-2-ethylhexyl sebacate are included for comparison.

The data shown on Table 10 indicate that the components of a Spec. MIL-O-5606 fluid as well as di-2-ethylhexyl sebacate are relatively stable for the 20 hour test at 500°F. under a nitrogen atmosphere. The Acryloid polymeric additive shows a tendency to decrease somewhat in viscosity. The viscosity decrease is not accompanied by indications of decomposition of the ester group or the formation of volatile products.

Table 8

PUMP PERFORMANCE STUDIES WITH LOW VISCOSITY HYDRAULIC FLUIDS

Tests conducted with Vickers Model PF-17-3911-10ZEL piston pump on PRL #3 pump test stand

Pump Test No.	240	245	246	247	248	249
Test Fluid	PRL 3115	PRL 3414	PRL 3415			
Base Stock, Wt.%	Typical Spec. MIL-0-5606 Fluid	XCT White Oil(1) 94.6	Kendall C-13(2) 94.6			
Antioxidant, Wt.%		Paranox 441 0.4	Paranox 441 0.4			
Anti-Wear Additive, Wt.%		Tricresyl Phosphate 5.0	Tricresyl Phosphate 5.0			
Viscosity at 100°F., cs.	14.4	3.27	2.18			
Viscosity at Test Temp., cs.	14.4	3.27	2.18	1.40	1.06	2.18
Pump Speed, r.p.m.	3600	3600	3600	3600	3600	3600
Pump Inlet Temp., °F.	100	100	100	150	200	100
System Pressure, p.s.i.	2900	3000	3000	2950	2750	3000
Test Time, hrs.	52	24	24	11	1	0.5
Average Flow Rate, g.p.m.(3)	3.10	3.04	3.00	2.89	2.76	3.00(4)

(1) Narrow boiling fraction of highly refined naphthenic gas oil obtained from the Standard Oil Company of New Jersey.
(2) Narrow boiling gas oil from Pennsylvania crude obtained from Kendall Refining Company.
(3) Flow rates are an average for the entire test time.
(4) Tests 246 and 249 were conducted on the same test fluid under the same conditions. The resultant flow rates indicate that the volumetric efficiency has not been altered by tests 247 and 248.

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JANUARY 26, 1953

Table 9

EFFECT OF BULK OIL TEMPERATURE ON THE WEAR CHARACTERISTICS OF SEVERAL LUBRICANTS IN THE SHELL FOUR-BALL WEAR TESTER

Test Conditions Include: Test Time = 1 Hour; Test Temperature as Indicated; Test Speed = 850 r.p.m.; Steel Balls = SKF Industries Grade #1 (0.5-Inch Diameter) Steel Ball Bearings, PRL Batch #8.

Test Fluid PRL 3090 = Necton 42, a low pour point mineral oil fraction having 32.3 centistokes viscosity at 100°F. + 0.4 Wt.% Paranox 441.
PRL 3091 = 1.0 Wt.% Tricresyl Phosphate in PRL 3090.
PRL 2574 = Spec. 51-F-21 type fluid prepared without an anti-wear additive.
PRL 3078 = Spec. 51-F-21 fluid containing 1.0 Wt.% Tricresyl Phosphate.
PRL 2429 = Di-2-Ethylhexyl Sebacate.
PRL 2860 = 1.0 Wt.% Tricresyl Phosphate + 0.4 Wt.% Paranox 441 in Di-2-Ethylhexyl Sebacate.
PRL 3069 = Experimental Gear Box Lubricant prepared by Rohm and Haas. Contains 1.0 Wt.% Tricresyl Phosphate and 7.5 Wt.% Santopoid S.
PRL 3077 = Experimental ester-base hydraulic fluid prepared without an anti-wear additive.
PRL 3039 = Experimental ester-base hydraulic fluid containing 1.0 Wt.% Tricresyl Phosphate.

PRL No.	Average Wear Scar Diameter, mm., for Steel-on-Steel Bearing Surfaces: 1 Kilogram Load, Test Temperature, °F.					10 Kilogram Load, Test Temperature, °F.					40 Kilogram Load, Test Temperature, °F.				
	167	266	300	351	399	167	266	300	351	399	167	266	300	351	399
3090	0.22	0.28	0.32	0.38	0.30	0.58	0.58	0.56	0.39	0.35	0.56	0.64	0.84	0.84	-
3091	0.14	0.15	0.17	0.18	0.25	0.33	0.26	0.28	0.28	0.33	0.67	0.84	0.71	0.91	-
2574	0.35	0.44	0.38	0.41	0.33	0.56	0.65	0.56	0.57	0.51	0.66	0.76	0.84	0.93	0.91
3078	0.15	0.16	0.15	0.15	0.14	0.22	0.22	0.25	0.23	0.23	0.44	0.54	0.70	0.97	0.84
2429	0.26	0.49	0.46	0.44	0.52	0.55	0.54	0.58	0.78	0.84	0.60	0.91	0.97	1.04	1.19
2860	0.14	0.17	0.15	0.16	0.18	0.25	0.25	0.26	0.26	0.30	0.38	0.80	0.91	0.97	0.97
3069	0.27	0.32	0.32	0.58	0.57	0.36	0.43	0.47	0.78	0.76	0.50	0.55	0.70	0.91	0.91
3077	0.32	0.46	0.44	0.50	0.58	0.63	0.70	0.81	0.97	1.04	0.84	0.97	0.97	1.10	1.10
3039	0.18	0.16	0.16	0.18	0.20	0.28	0.44	0.59	0.50	0.58	0.91	0.91	0.97	0.84	0.74

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JANUARY 26, 1953

The viscosity decrease is believed to be attributable to thermal depolymerization. Thermal tests at 500°F. with the mineral oil base stock, anti-tack component, tricresyl phosphate, and di-2-ethylhexyl sebacate show no appreciable evidence of molecular decomposition. The test conducted at 500°F. in the closed pressure cylinder on a commercial Spec. MIL-O-5606 hydraulic fluid indicates that there is no significant formation of volatile products. This is indicated by the low pressure at the end of the test at 500°F. and the lack of residual pressure upon cooling to room temperature.

These data indicate that a Spec. MIL-O-5606 fluid shows adequate thermal stability up to its normal boiling point (500°F.). In general, it has been found that oxidation dominates over thermal decomposition at high temperatures for mineral oil- and ester-base hydraulic fluids and lubricants. Spec. MIL-O-5606 hydraulic fluid is no exception to this trend.

Oxidation and Corrosion Stability. The oxidation stability and corrosion behavior are two of the most important properties of hydraulic fluids and lubricants. Their oxidation and corrosion behavior play a large part in governing fluid life, or the length of time between oil changes in service. These two properties become more important with increasing operating temperatures. The rate of oxidation and corrosion increases rapidly, and the induction period, or stable life, decreases rapidly, with increasing temperature. An oxidation and corrosion stability of 168 hours at 250°F. is afforded by the specification requirements for MIL-O-5606 hydraulic fluids. To fulfill this requirement, only a so-called low temperature oxidation and corrosion inhibitor is required. This inhibitor is believed to be of the hindered phenol type in most commercial preparation.

The effect of temperature on the stable life, or induction period, for a typical Spec. MIL-O-5606 fluid is shown on Figure 7. A similar curve is obtained for a Spec. MIL-O-5606 hydraulic fluid prepared by this Laboratory using 0.4 weight per cent Paranox 441 as the oxidation inhibitor.

These data indicate that the stable life of the hydraulic fluid decreases by a factor of 10 for every 60°F. increase in temperature. At 347°F. the stable life has been reduced to about 10 to 15 hours. This compares with a stable life of about 4,000 hours at 200°F. and 200 hours at 270°F. These data indicate that a typical Spec. MIL-O-5606 fluid has essentially no stable life under the oxidation conditions used at 400°F. and above. Stable life refers to the period during which little or no oxygen is absorbed by the test fluid even though there is plenty of oxygen available. During this interval most of the changes in the fluid's properties are small in magnitude. At temperatures above which there is essentially no stable life, the role of the conventional oxidation inhibitor is that of reducing the rate of oxidation, rather than of suppressing the oxidation entirely. In this latter region the oxidative deterioration is generally a direct function of the amount of oxygen in contact with the test fluid.

Table 10

THERMAL STABILITY OF VARIOUS COMPONENTS OF SPEC. MIL-O-5606 HYDRAULIC FLUID AT 500°F.

Tests conducted at 500 ± 5°F. for a period of 20 hours. Except where otherwise noted the fluid charge is 25 ml., and the test tubes used are sealed with a U-tube containing approximately 3 ml. of test fluid. Prior to the start of the test the volume of the sealed tube is replaced approximately 4 times with nitrogen. The nitrogen is introduced above the surface of the test fluid by means of a sealed-in capillary tube.

Test Fluid Composition	Centistoke Viscosity at 100°F. Original	Final	% Change	% Loss in Weight(2)	Neut. No. (Mg. KOH/gm. Oil) Orig.	Final
PRL 3115 (Commercial Spec. MIL-O-5606)(1)	14.1	9.85	-30	0.0	0.0	0.6
PRL 3115	14.1	9.51	-33	4.0	0.0	0.4
XCT White Oil	2.98	3.04	+2	2.0	0.0	0.2
Voltesso 36	9.50	9.59	+1	0.0	0.1	0.2
Di-2-Ethylhexyl Sebacate (not a -5606 component)	12.8	12.8	0	2.0	0.1	2.8
Tricresyl Phosphate	38.3	41.4	+8	2.0	0.2	3.5
10.0 Wt.% Acryloid HF-855 in Voltesso 36	46.2	27.7	-40	0.0	0.1	0.6
55.9 Wt.% Acryloid HF-855 in XCT White Oil	1179	886	-25	2.0	1.3	3.5

(1) This test conducted in a stainless steel cylinder which has a [illegible] volume of 46 ml. The fluid charged was 20 ml. (17 grams). Prior to starting the test the system is purged with nitrogen. The system is then sealed and the test started. Maximum system pressure during test was 35 p.s.i. The residual final pressure at room temperature was 0 p.s.i. The pressure of the nitrogen at 500°F. is about 15 p.s.i.

(2) Per cent loss in weight is valid to ± 2 per cent.

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Oxidation and corrosion tests with a typical commercial Spec. MIL-O-5606 hydraulic fluid are shown on Table 12. These tests cover temperatures from 250° to 500°F. Two different kinds of tests have been made. The majority of the tests shown have been conducted using the procedures and techniques set forth in Spec. MIL-O-5606. Two tests using the PRL thin film oxidation and corrosion test are also included. The thin film oxidation and corrosion test emphasizes the effect of large metal catalyst areas on thin films of oil in intimate contact with air. A detailed description of the thin film oxidation and corrosion procedure can be found in the Appendix of report PRL 6.1-Jan52.

Briefly the thin film procedure consists of allowing the test fluid to flow by gravity in a thin film over 2,000 sq. cm. of intimately mixed steel and copper jack chain (1,000 sq. cm. of each metal). At the same time, air is forced upwards (countercurrent) through the chain and over the falling oil film. The fluid is lifted from a reservoir below the jack chain packing to the top of the jack chain by means of a small bucket type lift pump. The oil cycling rate is about 75 ml. per minute. This test procedure is somewhat more severe than the Spec. MIL-O-5606 type oxidation and corrosion test. This test places particular emphasis on the dirtiness tendencies of the oil.

The 168 hour tests at 250°F. are shown on Table 12 to illustrate the minor property changes that occur within the induction period of a typical Spec. MIL-O-5606 fluid, in the specification oxidation and corrosion test as well as in the thin film oxidation and corrosion test. The data from the thin film test at 250°F. indicate slightly larger property changes in all cases than for the comparable test under Spec. MIL-O-5606 test conditions.

The oxidation and corrosion tests at 347°F. and higher are all beyond the stable life of the fluid. That is, all of these fluids after the test are in a state of incipient or severe oxidation. In the case of the 347°F. Spec. MIL-O-5606 type oxidation and corrosion test, the stable life of the fluid is about 12 to 14 hours under these conditions, compared with the test time of 24 and 36 hours. The thin film test at 347°F. indicates that the stable life of the fluid was exceeded in 12 hours under these conditions. The thin film test, for a lesser degree of oxidation than the Spec. MIL-O-5606 type test, shows more dirtiness.

Another point should be emphasized concerning the 347°F. tests. The 130°F. viscosity after all of the 347°F. tests show a decrease, while the 0°F. viscosity shows little decrease or an increase. These data are typical for the region of incipient oxidation of low viscosity mineral oil-Acryloid blends. This viscosity decrease is not a thermal phenomenon of the type illustrated in the previous section. Viscosity decrease of Spec. MIL-O-5606 type fluids from thermal effects begins at about 450°F. Thermal effects are believed to be a factor in the viscosity changes noted in the 450° and 500°F. oxidation and corrosion tests.

Previous oxidation studies at 250° and 347°F. have indicated that mineral oils of the type used as base stocks and anti-tack

components in Spec. MIL-O-5606 fluids show a steady increase in viscosity with incipient oxidation. An Acryloid HF 858 solution of the same mineral oils shows an initial decrease in high temperature viscosity (130°F.) with incipient oxidation. Upon further oxidation there is a subsequent increase in high temperature viscosity. In all cases at 347°F. and lower, the -40°F. viscosity shows a steady increase with incipient oxidation. The overall effect of a decreasing high temperature viscosity coupled with an increasing low temperature viscosity results in an increase in A.S.T.M. slope. The cause of this behavior is not known to this Laboratory. As pointed out previously, this phenomenon is not attributable to simple thermal depolymerization. This can be seen by comparing the viscosity behavior on oxidation at higher temperatures where thermal degradation is known to occur. Under these conditions, as shown on Table 12 (data at 450° and 500°F.), the viscosity values at 130° and 0°F. show a fairly uniform decrease.

The results at 450° and 500°F., given on Table 12, differ from those at 347°F. discussed above in that the tests at the higher temperatures show no induction period. That is, oxygen absorption begins immediately in these tests. In the 450° to 500°F. temperature range, the rate of oxidation is proportional to the amount of oxygen available. These tests have, therefore, been conducted at low air rates.

The air rate of 0.6 liters per hour is still quite large in terms of air leakage into a sealed or pressurized hydraulic system. The data on Table 11 give the equivalent minimum volume of air that would be required to produce the indicated amount of oxidation in a hydraulic system of 5 gallons capacity. These data assume that all of the oxygen present in the air reacts with the hydraulic fluid. This requires very intimate contact between the air and fluid for extended periods. The data on Table 11 are calculated for the three oxidation tests conducted at 450° and 500°F. These are the only tests for which quantitative oxygen absorption data have been obtained.

Table 11

Oxidation Conditions for Spec. MIL-O-5606 Fluids on Table 13			Approx. Min. Cu. Ft. of Air at 32°F. and 760 mm. Hg Required to Produce an Equivalent Degree of Oxidation in 5 Gal. of Fluid
Test Temp., °F.	Test Time, Hrs.	Air Rate, Liters/Hr.	
450	24	0.6	90
500	24	0.6	90
500	20	5.0	625

These data illustrate that sizeable quantities of air have to enter a system to produce the oxidative deterioration shown on Table 12

under the severe high temperature conditions used. The oxidation and corrosion data at 450° and 500°F., compared with the thermal stability data at 500°F., indicate clearly the advantages of using a closed hydraulic system, or at least a system with a limited air contact in this high temperature range.

The corrosion values for all of the oxidation and corrosion tests shown on Table 12 are low. It should be noted that magnesium has been omitted from the tests at 450° and 500°F. It has been found in previous studies that the oxidation of mineral oils and many synthetics at temperatures in the region of 400° to 500°F. always result in high magnesium corrosion. Magnesium corrosion would be anticipated in high temperature hydraulic systems where hydraulic fluid oxidation is encountered, even though the magnesium exists in a portion of the systems where temperatures are well below 400°F.

Some oxidation and corrosion studies have been conducted with Spec. MIL-O-5606 and similar fluids to study the interaction of individual metals and metals other than the five listed in the MIL-O-5606 specification. The results of conventional Spec. MIL-O-5606 oxidation and corrosion tests but modified by the inclusion of lead-indium coated silver-plated steel or copper-beryllium are shown on Table 13. The Spec. 51-F-21(Ord) fluid is prepared from essentially the same constituents as Spec. MIL-O-5606. The essential difference between these two specification fluids is in viscosity level.

It can be seen from the data on Table 13 that the corrosion of lead-indium coated silver-plated steel and copper-beryllium alloy are within the specification limit in all tests. In the case of the lead-indium coated silver-plated steel, however, there are signs of incipient corrosion and the values would be considered borderline. It can be noted that the Spec. 51-F-21 fluid also gives borderline copper corrosion. There is no indication in any of these tests that the inclusion of lead-indium coated silver-plated steel or copper-beryllium alloy has caused any deleterious effects on the fluid under these test conditions.

Several metals have been studied individually in an oxidation test for their effect on the stable life of Voltesso 36. Voltesso 36 is a naphthenic mineral oil fraction of the type used as a base stock, or anti-tack constituent, in Spec. MIL-O-5606 hydraulic fluid. The data obtained for the stable life of Voltesso 36 inhibited with Paranox 441, in the presence of various metals, is shown on Table 14. These data may also be considered typical of a complete Spec. MIL-O-5606 fluid of high quality. A temperature of 300°F. was chosen for the stable life tests to reduce the stable life values to a reasonable time for testing. These data indicate that copper, bronze, and silver-plated steel cause an appreciable drop in the stable life of the fluid. Magnesium and steel show some trend toward reducing the stable life. The stable life in the presence of lead, cadmium, and aluminum is essentially the same as the stable life in the absence of metals.

In addition to the stable life, the total test time and the amount of metal corrosion during the test is shown on Table 14. The difference between the test time and the stable life is the amount of time during which the fluid was undergoing significant oxidation. It is interesting to note, therefore, that severe corrosion of the metals did not take place even in the presence of oxidized oil of the Spec. MIL-O-5606 type. It can also be noted that measurable corrosion of the metal specimens is not necessary to cause an appreciable reduction in the stable life of the fluid. This reduction of stable life by metals without undergoing appreciable corrosion has been noted previously for both mineral oil and synthetic fluids. These oxidation and corrosion data indicate that some of the metals tested are less desirable than others because of their ease of corrosion or their tendency to promote oxidation. However, none of the metals evaluated in Tables 13 and 14 indicate sufficient prooxidant activity (reduction in stable life) to be categorically eliminated from hydraulic systems containing high quality Spec. MIL-O-5606 fluids. Corrosion of all of the metals discussed in this report can be controlled under most normal operating conditions by high quality Spec. MIL-O-5606 hydraulic fluids.

It has been indicated previously that it is desirable to exclude magnesium from systems where high temperatures and liquid water or oxidized oil exist together. Cadmium-plated steel has also given erratic corrosion behavior with mineral oil and synthetic hydraulic fluids. The data indicate that it is possible to produce fluids of satisfactory stability with respect to all of the Spec. MIL-O-5606 requirements and, in addition, give low metal corrosion with the metals discussed on Tables 13 and 14, but still give unsatisfactory behavior with respect to cadmium corrosion. It would be desirable to eliminate cadmium completely from the portion of the hydraulic system coming in contact with the fluid.

<u>Miscellaneous Physical Properties</u>. This Laboratory receives frequent requests for various physical properties of Spec. MIL-O-5606 fluids for use primarily in engineering and design calculations. Many of these properties have been measured or extrapolated from typical Spec. MIL-O-5606 and similar fluids. While there is some variation in these properties from batch to batch and from manufacturer to manufacturer, it is believed that the values given in the following tables and figures are sufficiently accurate to be used in engineering calculations for equipment designed around Spec. MIL-O-5606 hydraulic fluid.

The effect of pressure on density for a Spec. MIL-O-5606 fluid is shown on Figure 8. The data are plotted in Figure 8 so that the density ratio at any given pressure and temperature can be determined. The density at atmospheric pressure at the same temperature is then multiplied by this ratio to give the density at the desired pressure. For example, at 3,000 p.s.i. and 100°F., it can be seen from Figure 8 that the ratio of the density at this pressure and temperature to the density at atmospheric pressure and 100°F. temperature is approximately 1.0127. When this value is multiplied by 0.827 which is the fluid's

Figure 7 PRL 6.3-Dec53

OXIDATION BEHAVIOR OF SPECIFICATION MIL-O-5606 TYPE FLUIDS
AS A FUNCTION OF TEMPERATURE

TECHNIQUE AND PROCEDURE IN ACCORDANCE WITH SPEC. MIL-O-5606.

TEST CONDITIONS INCLUDE: TEST TIME AND TEST TEMPERATURE AS INDICATED; AIR RATE = 10 ± 1 LITERS PER HOUR; TEST FLUID CHARGED = 100 ML.; AND METAL CATALYSTS PRESENT AS SPECIFIED.

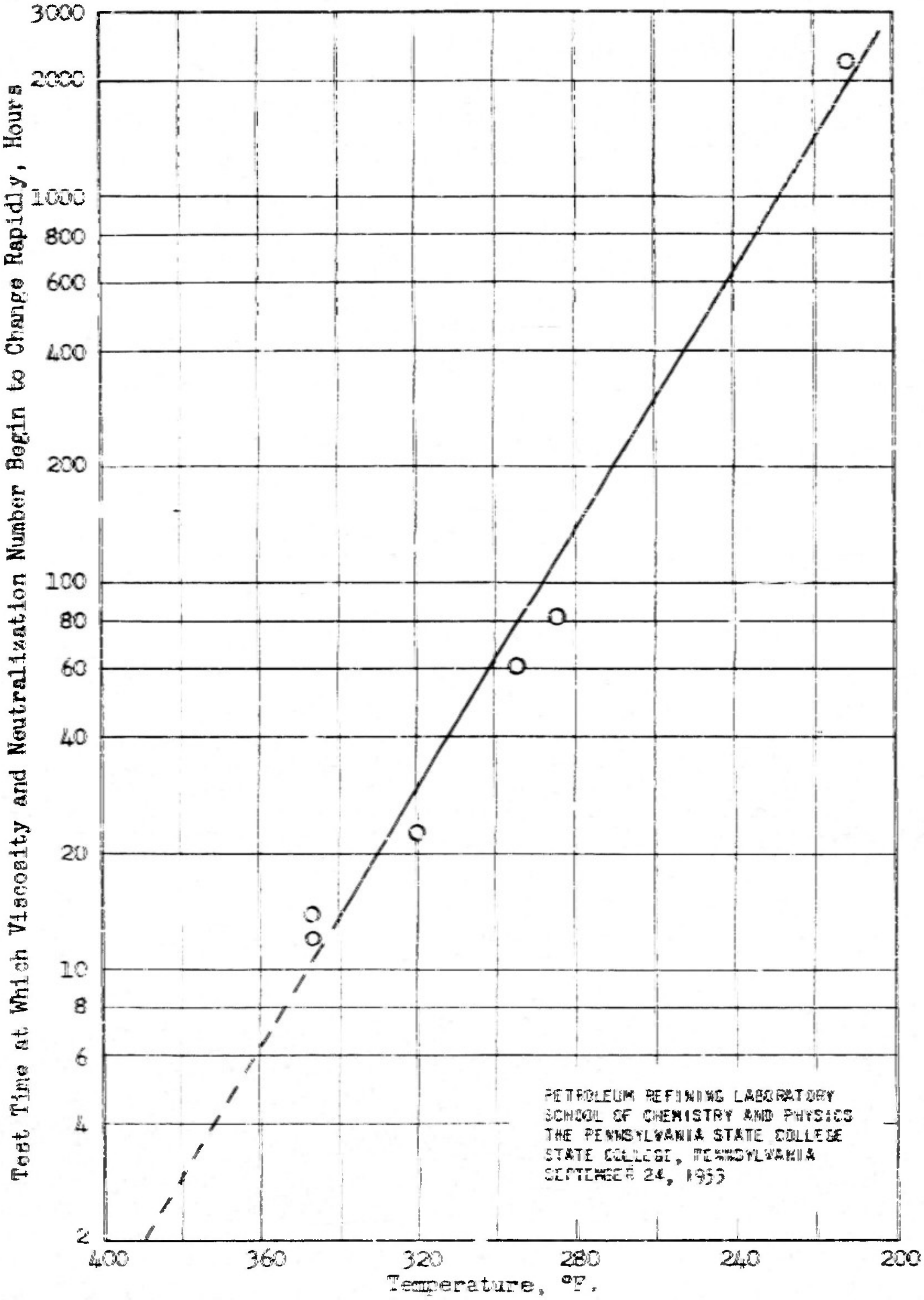

Table 12

OXIDATION AND CORROSION CHARACTERISTICS OF SPEC. MIL-O-5606 TYPE FLUIDS AT SEVERAL TEMPERATURES

TEST CONDITIONS: BULK OIL TYPE TEST: TEST TEMPERATURE, TEST TIME, AND AIR RATE AS INDICATED; TEST FLUID CHARGED = 100 ML.; AND CATALYST = A 1-INCH SQUARE OF EACH OF THE METALS INDICATED. PROCEDURE AND TECHNIQUE IN ACCORDANCE WITH SPEC. MIL-O-5606.
THIN FILM TYPE TEST: TEST TEMPERATURE, TEST TIME, AND AIR RATE AS INDICATED; TEST FLUID CHARGED = 50 ML. AND CATALYST = 1000 SQ. CM. EACH OF COPPER AND STEEL JACK CHAIN. PROCEDURE AND TECHNIQUE ARE DESCRIBED IN APPENDIX A, REPORT PRL 6.1-JAN52.

TEST TEMPERATURE, °F.	250	250	347	347	347	450	500	500
TEST TIME, HOURS	168	168	12	24	36	24	24	20
AIR RATE, LITERS/HR.	10	10	10	.10	10	0.6	0.6	5
TYPE TEST	BULK OIL	<- - - THIN FILM	- - - ->	<- - - -	- - - -	BULK OIL - - -	- - - -	- - ->
OVERALL LIQUID LOSS, WT.%	2	-	10	0	3	1	8	8
% CHANGE IN CENTISTOKE VISCOSITY								
AT 130°F.	+3	+49	-3	-53	-34	-59	-59	-49
AT 0°F.	+8	+21	+106	-3	-	-43	-20	-
NEUT. NO. (MG. KOH/GM. OIL):								
ORIGINAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FINAL	0.1	0.3	8.6	2.2	6.3	1.1	1.7	4.0
A.S.T.M. UNION COLOR:								
ORIGINAL	-(1)	-(1)	-(1)	-(1)	-(1)	-	-	-
FINAL	4-1/2	7	>8	7	>8	-	-	-
WT.% INSOLUBLE MATERIAL	NONE	TRACE	0.6	TRACE	0.1	TRACE	TRACE	1.0
FINAL CATALYST CONDITION								
APPEARANCE								
COPPER	DULL	DULL(2)	DULL(2)	DULL	DULL	DULL	DULL	DULL
STEEL	BRIGHT	DULL(3)	DULL(3)	DULL	DULL	DULL	DULL	DULL
ALUMINUM	BRIGHT	-	-	DULL	DULL	BRIGHT	BRIGHT	BRIGHT
MAGNESIUM	BRIGHT	-		DULL	CORRODED	-	-	-
CADMIUM	BRIGHT	-	-	-	-	-	-	-
WT. LOSS (MG./SQ. CM.)								
COPPER	0.15	0.00(2)	0.18(2)	0.19	0.17	0.02	0.06	0.16
STEEL	0.04	+0.02(3)	0.07(3)	0.07	+0.02	+0.02	0.00	0.09
ALUMINUM	0.01	-	-	0.02	0.12	0.01	0.00	0.02
MAGNESIUM	0.02	-	-	0.02	0.29	-	-	-
CADMIUM	0.06	-	-	-	-	-	-	-

(1) FLUID IS DYED RED AND NO COLOR DETERMINATION IS MADE.
(2) CATALYST IS 1000 SQ. CM. OF COPPER JACK CHAIN.
(3) CATALYST IS 1000 SQ. CM. OF STEEL JACK CHAIN.

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SEPTEMBER 14, 1953

Table 13

CORROSION STUDIES WITH MINERAL OIL HYDRAULIC FLUIDS

TEST PROCEDURE AND TECHNIQUES IN ACCORDANCE WITH SPEC. MIL-O-5606. LEAD-INDIUM COATED SILVER-PLATED SPECIMENS HAVE BEEN INCLUDED IN THESE TESTS. THE LEAD-INDIUM SURFACE IS SUBSTITUTED FOR CADMIUM-PLATED STEEL IN THIS TEST. ALL OF THE METAL CATALYSTS EXCEPT THE LEAD-INDIUM SPECIMEN ARE 1" X 1" X 20 GAGE. THE LEAD-INDIUM CATALYST IS A SECTION OF AIRCRAFT PISTON ENGINE BEARING HAVING APPROXIMATELY 1 SQ. IN. OF LEAD-INDIUM SURFACE ON A 1 SQ. IN. STEEL BACKING. ALL TESTS ARE CONDUCTED AT AN AIR RATE OF 10 ± 1 LITERS PER HOUR.

TEST FLUID	PRL 3115(1)	PRL 2828(2)	PRL 3115(1)
TEST TEMPERATURE, °F.	250	250	250
TEST TIME, HOURS	168	168	168
LIQUID LOSS, WT.%	3	6	4
% CHANGE IN VISCOSITY			
AT 130°F.	+7	+10	+6
AT 0°F.	+10	+24	-
NEUT. NO. (MG. KOH/GM. OIL)			
ORIGINAL	0.0	0.3	0.0
FINAL	0.1	0.5	0.0
A.S.T.M. UNION COLOR			
ORIGINAL	6	2	5
FINAL	6	5	5
WT.% INSOLUBLE MATERIAL	NONE	TRACE	NONE
FINAL CATALYST CONDITION			
APPEARANCE			
COPPER	DULL	CORRODED	-
STEEL	DULL	COATED	-
ALUMINUM	DULL	DULL	-
MAGNESIUM	DULL	DULL	-
LEAD-INDIUM	DULL	DULL	-
COPPER-BERYLLIUM	-	-	DULL
WT. LOSS (MG./SQ. CM.)			
COPPER	0.06	0.23	-
STEEL	0.02	+0.16	-
ALUMINUM	+0.02	0.02	-
MAGNESIUM	0.02	0.02	-
LEAD-INDIUM	+0.20	0.13	-
COPPER-BERYLLIUM	-	-	+0.03

(1) COMMERCIAL SPEC. MIL-O-5606 FLUID PREPARED BY THE STANDARD OIL COMPANY OF NEW JERSEY.
(2) COMMERCIAL SPEC. 51-F-21 (ORD) FLUID PREPARED BY THE STANDARD OIL COMPANY OF NEW JERSEY.

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JULY 27, 1953

Table 14

PRL 6.3-Dec53

EFFECT OF CATALYST METALS ON OXIDATION STABILITY

Test Procedures and Techniques in Accordance with Spec. MIL-O-5606.
Test Conditions Include: Test Temperature = 300 ± 3°F.; Test Time as Indicated; Test Fluid = 100 ml.; Air Rate = 10 ± 1 liters per hour; Metal Catalyst = One Inch Squares of Indicated Metals; Test Fluid = Voltesso 36(2) + 0.4 Wt.% Paranox 441.

Catalyst Metal	Approx. Stable Life, Hours(1)	Test Time, Hrs.	Catalyst Wt. Loss, mg./sq. cm.
No Catalyst	300	365	-
Copper, Steel, Aluminum, Magnesium, and Cadmium-Plated Steel	230	360	0.0[illegible] +0.06, +0.05, +0.10, 0.37
Copper	190	212	0.02
Bronze	190	240	0.19
Steel	250	365	+0.08
Sheet Lead	300	330	0.10
Silver-Plated Steel	140	220	0.29
Cadmium-Plated Steel	280	310	0.02
Aluminum	280	311	0.00
Magnesium	245	264	0.03

(1) Stable life determined by the sharp break in the curve of neutralization number versus time.
(2) Voltesso 36 is a highly refined naphthenic gas oil typical of good quality base stocks for Spec. MIL-O-5606, Spec. 51-F-21(Ord), Spec. 51-F-23(Ord), Spec. MIL-L-7870 and Spec. AN-O-9.

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February 24, 1953

density at atmospheric pressure and 100°F., a value of 0.838 is obtained for the density of the fluid at 3,000 p.s.i. and 100°F.

The effect of pressure on the viscosity of a typical Spec. MIL-O-5606 hydraulic fluid has been calculated from data obtained from fluids of this class. These data are shown on Figure 9. The kinematic viscosity is plotted against absolute pressure in pounds per square inch. At a temperature of 100°F. and a pressure of 3,000 p.s.i., it can be seen that Spec. MIL-O-5606 hydraulic fluid increases in viscosity from approximately 14.2 (at 1 atmosphere pressure) to 21 centistokes. This represents an increase of 48 per cent. The rate of change in viscosity with pressure increases with decreasing temperature. At -40°F., the viscosity increase is 83 per cent for a pressure increase from one atomsphere to 3,000 p.s.i. The corresponding value for 200°F. is 36 per cent increase in viscosity.

The bulk modulus of elasticity has been calculated for Spec. MIL-O-5606 type hydraulic fluids. The bulk modulus of elasticity of a fluid is the reciprocal of the compressibility and can be defined by the equation:

$$B = \frac{\text{Stress}}{\text{Strain}} = \frac{(P - P_o)\,V_o}{(V_o - V)}$$

B = Bulk modulus of elasticity
P_o = Atmospheric pressure
P = Absolute pressure
V_o = Specific volume at P_o
V = Specific volume at P

Bulk modulus data for Spec. MIL-O-5606 fluid are calculated from the compressibility data presented in Figure 10. These data are tabulated in Table 15.

Table 15

BULK MODULUS VALUES FOR SPEC. MIL-O-5606 FLUID

All values calculated for 100°F.

Test Fluid	Pressure, p.s.i.	Sp. Vol. $cm.^3/gm.$	Average Bulk Modulus p.s.i. x 10^{-5}
Spec. MIL-O-5606 (14.2 cs. at 100°F.)	0	1.209	-
	1,000	1.203	2.2
	3,000	1.193	2.4

If the limits of error in reporting density to three decimal places are considered to be ± 0.001, the resultant error in bulk modulus

is $\pm$ 0.2 x 10^5 p.s.i. The compressibility of many mineral oils have been studied by Dow and Fink in this Laboratory*. Their conclusion is that the compressibility (and the bulk modulus) of essentially all petroleum derived mineral oils is the same within the limits of experimental error. The value for bulk modulus is not altered significantly by the Acryloid thickener used in formulating Spec. MIL-O-5606 type fluids.

The temperature function of bulk modulus has been determined for a typical Spec. MIL-O-5606 fluid. These data are shown on Figure 10, along with the effect of temperature on density. The solid line on the bulk modulus curve is for the average value over the range of 0 to 10,000 p.s.i. pressure. The dotted line is an extrapolated curve for the average value of 0 to 5,000 p.s.i. pressure.

The values for change in density with temperature shown on Figure 10 have been used to calculate the average cubical coefficient of expansion for the range of +130° to -40°F. The average values obtained are 7.9 x 10^{-4} cc./cc./°C. or 4.4 x 10^{-4} cc./cc./°F.

Data for specific heat and thermal conductivity of Spec. MIL-O-5606 type fluids are shown on Table 16. No appreciable differences in these values would be expected due to batch to batch variations.

Table 16

PHYSICAL PROPERTIES FOR SPEC. MIL-O-5606 FLUID

Temperature, °F.	Density g./ml.	Specific Heat B.T.U./lb./°F.	Thermal Conductivity B.T.U./Sq. Ft./Hr./(°F. per Ft.)
	Data for Typical Spec. MIL-O-5606 Mineral Oil Hydraulic Fluid		
-65	0.89	-	-
0	0.86	0.45	0.081
100	.83	0.50	0.079
200	0.79	0.55	0.076
300	0.75	0.60	0.074

<u>Conclusions</u>. The high temperature studies with Spec. MIL-O-5606 hydraulic fluid indicate that one of the limitations to high temperature operation is fluid volatility. The bulk base stock component of the fluid exhibits an initial boiling point of about 500°F. at 760 mm. Hg. Extensive evaporation of the base stock results in the formation of tacky or sticky films when Spec. MIL-O-5606 fluid is exposed to reasonably high temperatures (200°F. and upwards) in a thin film for extended periods of time when exposed to circulating air.

* Dow, R. B. and Fink, C. E., Journal of Applied Physics, <u>11</u>, 353 (1940).

Figure 8 PRL 6.3-Dec53

THE EFFECT OF PRESSURE ON THE DENSITY OF SPECIFICATION MIL-O-5606 TYPE HYDRAULIC FLUID

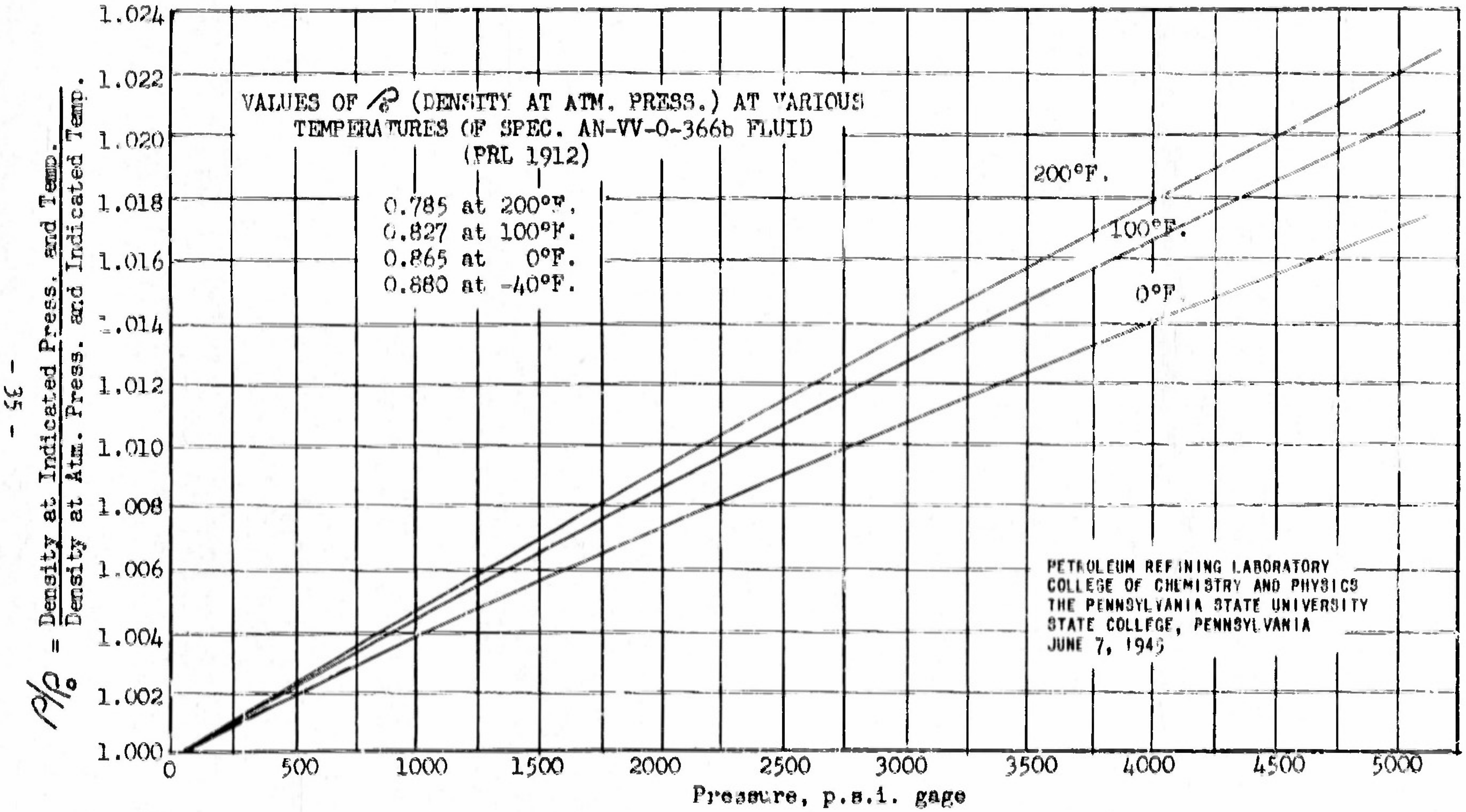
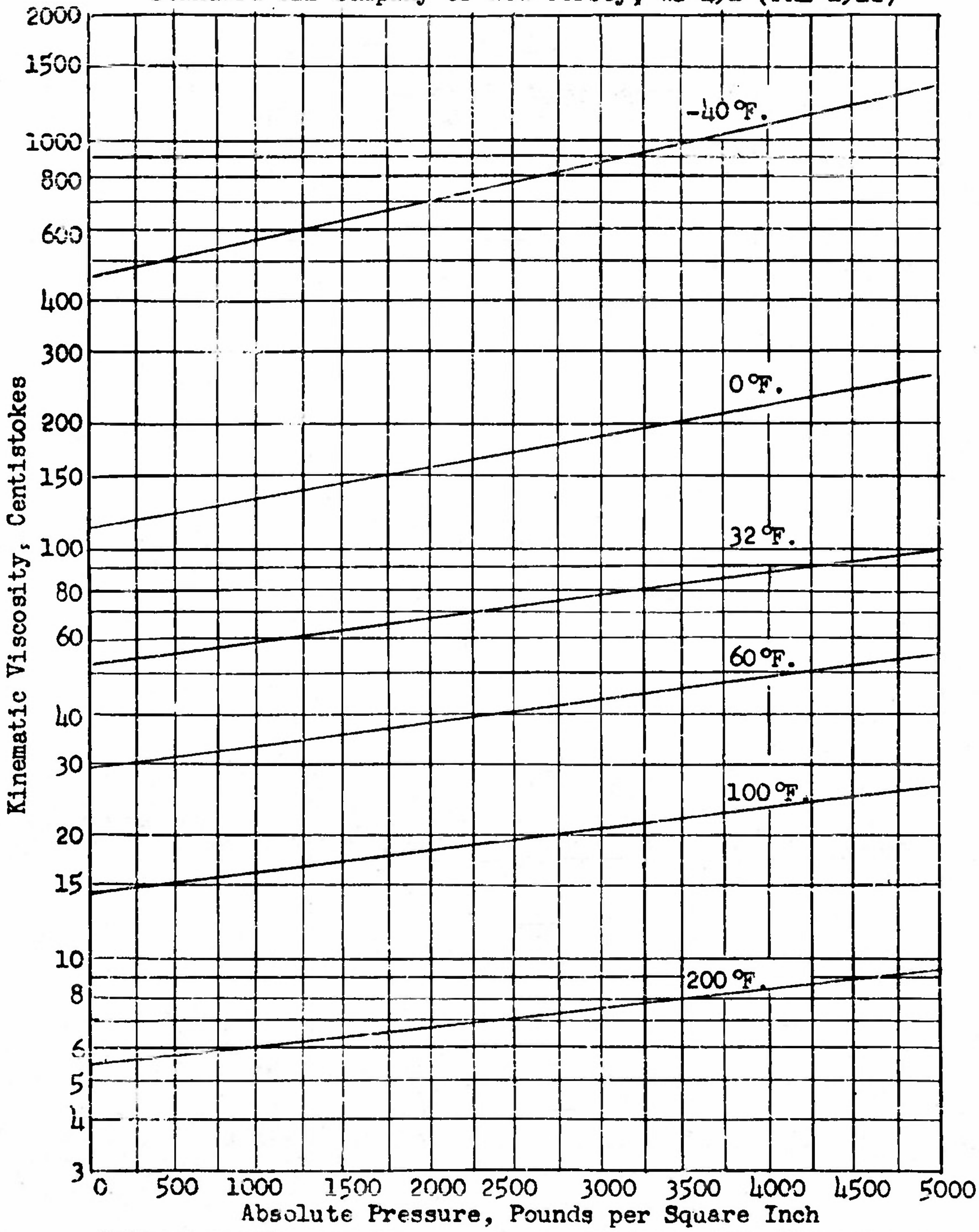


Figure 9 PRL 6.3-Dec53

EFFECT OF PRESSURE ON THE VISCOSITY OF A TYPICAL SPECIFICATION MIL-O-5606 TYPE FLUID

Data based on Spec. AN-VV-O-366b Fluid Prepared by the Standard Oil Company of New Jersey, WS-491 (PRL 1912)



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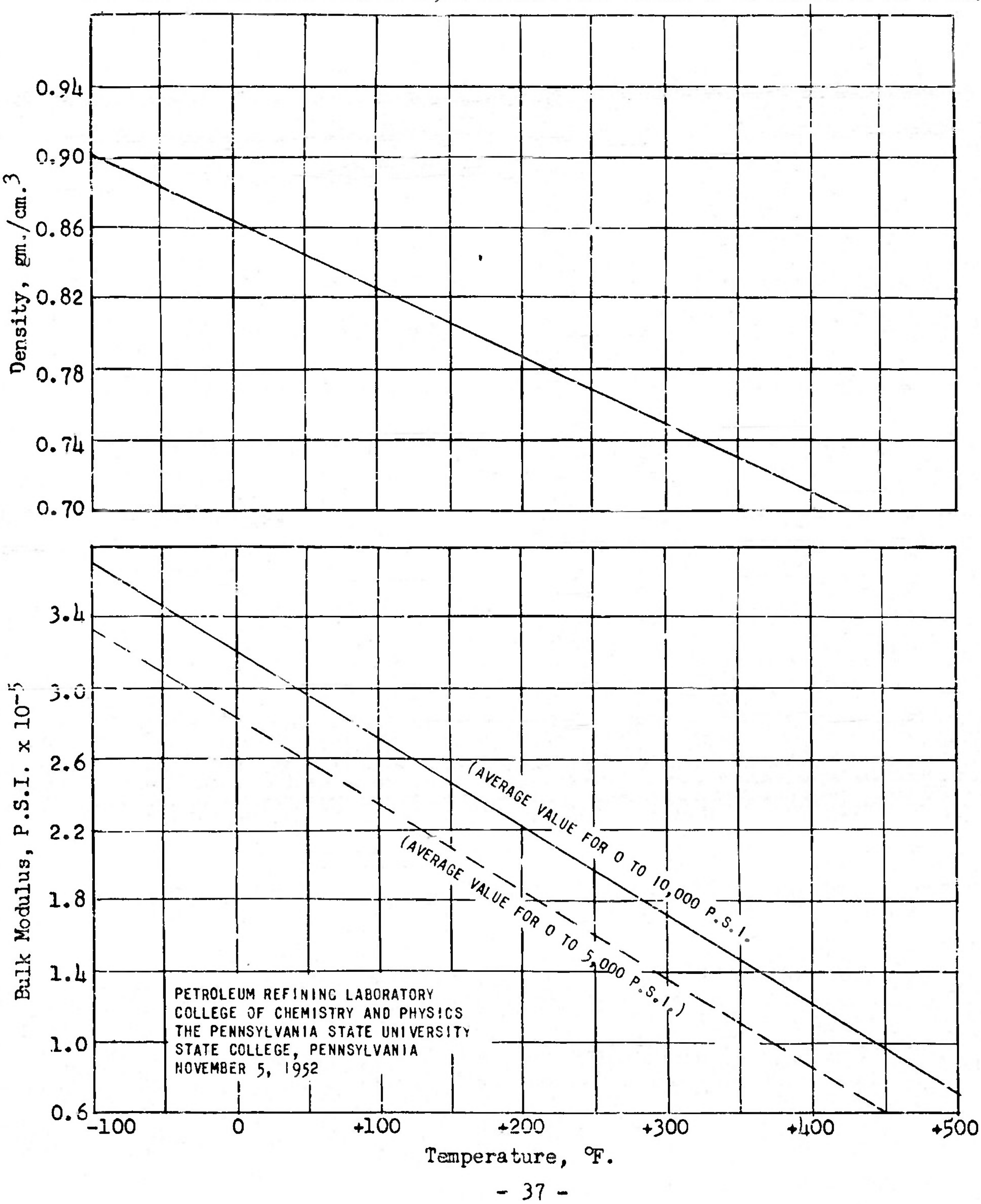
STATE COLLEGE, PENNSYLVANIA
JUNE 7, 1945

Figure 10

VARIATION OF BULK MODULUS OF ELASTICITY AND DENSITY WITH TEMPERATURE FOR A SPEC. MIL-O-5606 HYDRAULIC FLUID

TEST FLUID IS A COMMERCIAL SPEC. MIL-O-5606 HYDRAULIC FLUID PREPARED BY THE STANDARD OIL CO. OF N.J.



This problem of tacky film formation can be solved by: (1) changes in the mechanical design of hydraulic systems to reduce the amount of air in contact with oil films, and (2) the inclusion of a more effective anti-tack component such as di-2-ethylhexyl sebacate.

Tests indicate that Spec. MIL-O-5606 fluid has sufficient viscosity and lubricity at 400° to 500°F. to operate satisfactorily in properly designed high temperature hydraulic pumps. Such data are based on the operation of a standard Vickers piston pump at 200°F. on fluids with viscosity and lubricity properties at 200°F. that match those of Spec. MIL-O-5606 fluid at 400° to 500°F. These data further indicate that fluid volatility will be the limiting factor in high temperature pump operation.

All of the components as well as the finished Spec. MIL-O-5606 fluid show adequate thermal stability at 500°F. for extended periods. The conventional oxidation stability, or the length of time the fluid is inhibited against oxidation, for a Spec. MIL-O-5606 fluid decreases rapidly with increasing temperature. Stable life values for a typical fluid decrease from about 3,000 hours at 200°F., to 200 hours at 275°F., and to 10 to 15 hours at 347°F. There is essentially no induction period above 400°F. Test data indicate that the Spec. MIL-O-5606 fluid can be used for considerable lengths of time in the region of 347° to 500°F. if care is taken to control or to limit the amount of air or oxygen filtering into the hydraulic system (see Tables 12 and 13). A reasonable amount of oxygen can be assimilated by the hydraulic fluid without causing sufficient property changes to render the fluid inoperative. The extent of service life might effectively be increased for operations above 200°F. by the use of a closed hydraulic system pressurized by nitrogen or separated from the pressurizing medium by a diaphragm.

No appreciable metal corrosion has been noted in oxidation and corrosion tests with Spec. MIL-O-5606 fluids over the temperature range of 250° to 500°F. under conditions of incipient oxidation of the fluid.

The reduction in the stable life of Spec. MIL-O-5606 type hydraulic fluid by the presence of silver, copper, and some copper alloys is readily demonstrated. The extent of the reduction in stable life is not believed to be sufficient, however, to exclude these metals from hydraulic systems for this reason alone. The corrosion of cadmium plated surfaces by otherwise satisfactory hydraulic fluids makes it desirable to eliminate wherever possible the use of cadmium plated surfaces in hydraulic systems. The use of magnesium in hydraulic systems containing hot spots or bulk temperatures in excess of 250°F. is not recommended where liquid water and/or oxidized hydraulic fluid may exist or be formed at an appreciable rate.

Several physical properties of Spec. MIL-O-5606 including: viscosity as a function of pressure, density as a function of pressure, density as a function of temperature, the bulk modulus as a function of temperature, specific heat, thermal conductivity, and the cubical

coefficient of expansion have been measured and/or calculated. These properties are given primarily as an aid in engineering and design calculations.

In general, these studies show that temperatures up to 500°F. can be tolerated by Spec. MIL-O-5606 fluid under a variety of conditions. The formulation of specific limitations will require testing in actual hydraulic systems with the individual hydraulic system components.

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December 30, 1953